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Silvicultural Systems and Cutting Methods for Old-Growth Spruce-Fir Forests in the Central and Southern Rocky Mountains

Robert R. Alexander

Abstract

Guidelines are provided to help the forest manager and silviculturist develop even- and/or uneven-aged cutting practices needed to convert old-growth spruce-fir forests into managed stands for a variety of resource needs. Guidelines consider stand conditions, succession, windfall risk, and insect and disease susceptibility. Cutting practices are designed to integrate timber production with increased water yield, maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic viewing.

Cover Photo.—Old-growth spruce-fir forests, Fraser Experimental Forest, Colorado.

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Robert R. Alexander, ~~Chief Silviculturist~~
Rocky Mountain Forest and Range Experiment Station[1]

[1]Headquarters is in Fort Collins, in cooperation with Colorado State University.

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Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)—subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) forests (SAF Type 206) (Alexander 1980, Society of American Foresters 1980) are the predominant multiple-use forests in the central and southern Rocky Mountains. These forests occupy about 4.2 million acres of timberland with an estimated 47 billion board feet (INT 1/4 Rule) of sawtimber (Green and Van Hooser 1983). They grow on areas of moderate to high timber production potential. These forests also occupy the highest potential water yielding areas and provide habitats for a variety of wildlife, forage for livestock, summer and winter dispersed and developed recreational opportunities, and outstanding scenic beauty. In addition, much other land now covered by seral tree species, such as lodgepole pine (*Pinus contorta* Dougl. ex Loud.) and quaking aspen (*Populus tremuloides* Michx.), also has the potential to grow spruce and fir (Alexander 1977, Alexander and Engelby 1983).

NATURAL STANDS

AGE-CLASS DISTRIBUTION

Spruce-fir forests generally have an imbalance in age-class distribution. Most of the stocked area is in sawtimber, and the least is in seedling and sapling stands. The vast majority of these stands, therefore, are overmature and declining in vigor and soundness.

Only about 10% of the spruce-fir is classified as immature stands. Most of the poletimber became established after wildfires burned in the early 1900s. Because wildfires are random events and most fires burned a relatively small average area, poletimber stands of spruce-fir are scattered throughout the central and southern Rocky Mountains. About 8% of the spruce-fir forest lands are classified as seedling and sapling stands. These stands originated from either fires or cutting. Nearly 6% of timberland is classified as nonstocked. Failure of tree reproduction after fire or cutting accounts for some of the nonstocked area; but not all nonstocked lands can support commercial spruce-fir forests (Green and Van Hooser 1983).

REACTION TO COMPETITION AND DISTURBANCE

In the central and southern Rocky Mountains, Engelmann spruce is rated shade tolerant (Baker 1949). It is definitely more shade tolerant than associates such as ponderosa pine (*Pinus ponderosa* Laws), Rocky Mountain Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco), lodgepole pine, quaking aspen, blue spruce (*Picea pungens* Engelm.), and southwestern white pine (*Pinus strobiformis* Engelm.); but less than its most common associate, subalpine fir, and corkbark fir (*Abies lasiocarpa* var. *arizonica* (Merriam) Lemm.) and white fir (*Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.).

Engelmann spruce grows in at least 142 recognized habitat types, community types, and plant communities, and is either a co-climax with subalpine fir or a long-lived seral forest vegetation in most of them (Alexander 1985b). In the central and southern Rocky Mountains, Engelmann spruce and subalpine fir occur as either codominant mixtures or in nearly pure stands of either species. Elsewhere in the Rocky Mountains and associated ranges, subalpine fir is the major climax species. Engelmann spruce also may occur as a major climax species; but more often it is a persistent long-lived seral species. Pure stands of either species can be found throughout the Rocky Mountains, however (Alexander 1980).

Climax forests are not easily displaced by other vegetation; but fire, logging, and insects have significantly influenced the successional status and composition of spruce-fir forests. Complete removal of the stand by fire or logging results in such drastic environmental changes that spruce and fir usually are replaced by lodgepole pine, quaking aspen, or shrub and grass communities (Roe et al. 1970, Stahelin 1943, Whipple and Dix 1979). The kind of vegetation initially occupying the site usually determines the length of time it takes to return to a spruce-fir forest. It may vary from a few years, if the site is initially occupied by lodgepole pine or quaking aspen, to as many as 300 or more years if grass is the replacement community (fig. 1). Although the factors that deter-

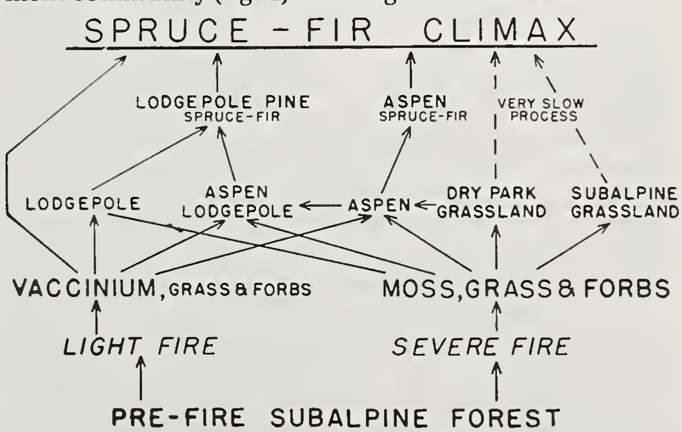

Figure 1.—Natural succession in central Rocky Mountain spruce-fir stands following fire (Stahelin 1943).

mine the kind of replacement stand are not fully understood, the nature of the disturbance and the habitat type are useful in predicting succession. Attacks by spruce beetle (*Dendroctonus rufipennis*, Kirby) usually have resulted in a change in the dominant element of the stand from spruce to fir. Because of its larger size and longer life, spruce usually regains its dominant position in the stand, only to be removed again by spruce beetles (Schmid and Frye 1977, Schmid and Hinds 1974).

STAND CONDITIONS

Old growth spruce-fir forests grow on a wide range of sites with a great diversity of stand conditions and characteristics. For example, although spruce-fir forests form climax or near-climax plant associations throughout the central and southern Rocky Mountains, they differ from most climax forests in that stands are not truly all-aged (Alexander 1985a, Hanley et al. 1975, LeBarron and Jemison 1953). Some stands are clearly single-storied, indicating that spruce forests can be grown under even-aged management. Other stands are two- or three-storied, and multistoried stands are not uncommon (Alexander 1973, Miller 1970). These may be the result of either past disturbances, such as fire, insect epidemics, or cutting, or the gradual deterioration of old-growth stands associated with normal mortality from wind, insects, and diseases. Gradual mortality is especially evident in the formation of some multistoried stands. However, some multistoried stands appear to have originated as uneven-aged stands, and are successfully perpetuating this age-class structure (Alexander 1985a, Hanley et al. 1975, Whipple and Dix 1979). Regardless of stand structure, trees may be uniformly spaced or they may grow in groups, clumps, or patches. Two or more stand conditions and/or characteristics frequently occur on the same tract.

The composition of spruce-fir forests varies considerably with elevation. At mid-elevations (10,000 to 11,000 feet), these forests are frequently pure spruce in the overstory with fir predominating in the understory. For example, in the central Rocky Mountains, spruce commonly makes up 70% or more of the overstory basal area, and fir from two-thirds to three-fourths of the understory and advanced reproduction (Alexander 1957, 1963, 1968; Hodson and Foster 1910, Oosting and Reed 1952). This composition in relation to structure has developed under natural conditions, because spruce is more exacting in its seedbed requirements and less able to compete with fir under low light intensities common to dense forests. Once established, however, spruce lives longer than fir and is less susceptible to disease (Alexander and Shepperd 1984, Alexander et al. 1984). Exceptions are stands recently attacked by spruce beetles, where fir is the dominant element in both the overstory and understory. At higher elevations in the central and southern Rocky Mountains, spruce may form essentially pure stands, while at lower elevations where sites are usually drier, the density of spruce relative to fir may be low. In these latter situations in the central Rocky Mountains, lodgepole pine, a long-lived seral species, or aspen frequently are more numerous in the overstory than spruce, especially on sites disturbed by logging or fire.

Advanced spruce and fir reproduction is likely to be older than it appears, because the early growth of both is slow. Spruce commonly takes from 20 to 40 years to reach a height of 4 to 5 feet, even under favorable conditions, whereas under a dense canopy, spruces 4 to 6 feet tall may be 75 or more years old (Oosting and Reed 1952). Spruce and fir reproduction suppressed for long periods of time will respond to release, however, and will make acceptable growth (Alexander 1968, McCaughey and Schmidt 1982).

DAMAGING AGENTS

WIND

Windfall is a common cause of mortality after any kind of initial cuttings in mature and overmature spruce-fir forests. Low stumpage values and the generally scattered pattern of windfall may prevent the salvage of blowdown. Not only is the volume of windthrown trees lost, but downed spruce trees provide ideal breeding grounds for the spruce beetle. The high endemic populations of beetles normally associated with old-growth spruce-fir forests can multiply rapidly to epidemic proportions in the windthrown trees and then emerge to attack living trees.

Windfall losses are heavy after any kind of partial cutting in spruce-fir forests. Less damage is associated with clearcutting, because only the boundaries between cut and uncut areas are vulnerable. Losses can be substantial along the boundaries of clearcuttings, however, particularly if no special effort is made to select windfirm boundaries (Alexander 1964, 1967).

While the tendency of spruce and fir to windthrow is usually attributed to a shallow root system, the development of the root system varies with soil and stand conditions. On medium to deep, well-drained soils, trees have a better root system than on shallow, poorly drained soils. Trees that have developed together in dense stands over long periods of time mutually protect each other, and do not have the roots, boles, or crowns to withstand sudden exposure to wind if opened up too drastically. If the roots and boles are defective, the risk of windthrow is increased. The presence of old windfalls in a stand is a good indicator of lack of windfirmness. Furthermore, regardless of the kind or intensity of cutting, or soil and stand conditions, windthrow is greater on some exposures than others (Alexander 1964, 1967, 1973). Exposures where windfall risk is below average, above average, or very high have been identified (fig. 2) as follows.

Low

1. Valley bottoms, except where parallel to the direction of prevailing winds, and flat areas.
2. All lower, and gentle middle north- and east-facing slopes.

3. All lower, and gentle middle south- and west-facing slopes that are protected from the wind by considerably higher ground not far to windward.

Moderate

1. Valley bottoms parallel to the direction of prevailing winds.
2. Gentle middle south and west slopes not protected to windward.
3. Moderate to steep middle, and all upper north- and east-facing slopes.
4. Moderate to steep middle south- and west-facing slopes protected by considerably higher ground not far to windward.

High

1. Ridgetops.
2. Saddles in ridges.
3. Moderate to steep middle south- and west-facing slopes not protected to windward.
4. All upper south- and west-facing slopes.

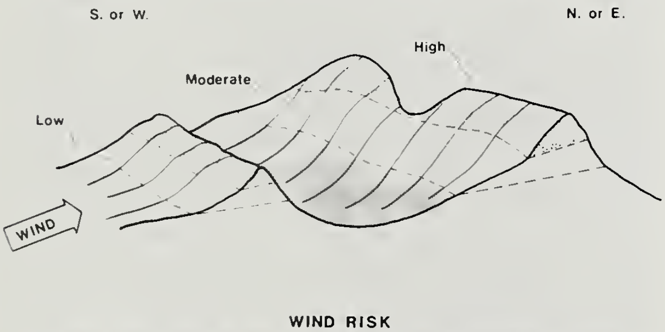

Figure 2.—Wind risk in relation to topographic exposure.

The risk of windfall in these situations is increased at least one category by factors such as poor drainage, shallow soils, defective roots and boles, and overly dense stands. Conversely, the risk of windfall is reduced if the stand is open grown or composed of young, vigorous, sound trees. All situations become very high risk if exposed to special topographic situations such as valley bottoms with steep side slopes that are parallel to the wind and become narrower in the direction of the wind (fig. 3), and gaps or saddles in ridges at higher elevations to windward that can funnel winds into the area (fig. 4).

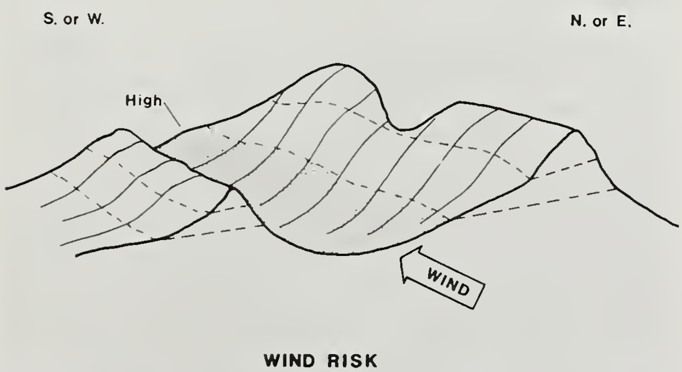

Figure 3.—Very high wind risk; valley bottoms parallel to the direction of the wind.

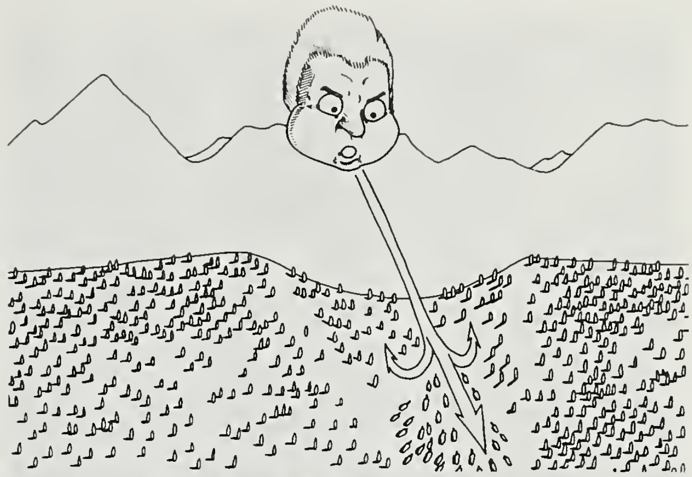

Figure 4.—Very high wind risk; winds funneled through a saddle in a ridgetop.

INSECTS

Keen (1952) listed many insect pests of Engelmann spruce. Of these, the spruce beetle is the most serious (Schmid and Frye 1977). It is restricted largely to mature and overmature spruce (Hopkins 1909; Massey and Wygant 1954; Sudworth 1900a, 1900b). One of the most damaging recorded outbreaks was in Colorado from 1939-51, when beetles killed nearly 4 billion fbm of standing spruce. Damaging attacks have been largely associated with extensive windthrow, where downed trees have provided an ample food supply needed for a rapid buildup of beetle populations (Massey and Wygant 1954, Wygant 1958). Cull material left after logging and road right-of-way clearing also has supported outbreaks, and there are many instances of heavy spruce beetle populations developing in scattered trees windthrown after heavy partial cutting (Wygant and LeJeune 1967). The beetle progeny then emerge to attack living trees, sometimes seriously damaging the residual stand. Occasionally heavy spruce beetle outbreaks have developed in overmature stands with no recent history of cutting or windfall; but losses in uncut stands that have not been subjected to catastrophic windstorms usually have been no greater than normal mortality in old growth (Alexander 1973).

Spruce beetles may emerge from May to July, and trees may be attacked from late May through early August. Beetles feed and breed in the phloem layer. The first evidence of attack is the red boring dust from entrance holes that usually accumulates in bark crevices on the boles and around the bases of infested trees (fig. 5). Small frass-clogged entrance holes may be visible in the bark. Pitch tubes usually are prevalent on the upper bole, where attacks terminate. The needles of killed trees usually turn yellowish green and fall about 1 year after attack; but they may remain green until the second year (Schmid and Beckwith 1971, Schmid and Frye 1977). Frass usually does not accumulate on the ground under windthrown trees or logging residue. Windthrown trees and logging residues do not show pitch tubes. Frass does accumulate in the bark on the bottom surfaces, however.

Figure 5.—Engelmann spruce attacked by bark beetles.

Beetles prefer downed material to standing trees; but if downed material is not available, standing trees may be attacked. Overmature trees of large diameter are attacked first; but if an infestation persists, beetles attack and kill smaller diameter trees after the larger trees in the stand are killed. In the central Rocky Mountains, susceptibility of spruce stands, in relation to location, decreases in the following order: (1) trees in creek bottoms, (2) better stands on benches and high ridges, (3) poorer stands on benches and high ridges, (4) mixed stands, and (5) immature stands (Knight et al. 1956, Schmid and Beckwith 1971). Analysis of past infestations suggests the following characteristics are associated with potential outbreaks: (1) single- or two-storied stands, (2) high proportions of spruce in the overstory, (3) basal area of 150 square feet per acre or more in older and larger trees, and (4) an average 10-year periodic diameter growth of 0.4 inch or less (Schmid and Hinds 1974).

Natural factors such as nematodes, insect parasites and predators, and woodpeckers normally maintain beetle populations at low levels, but generally fail to control populations under outbreak conditions. Extremely low temperatures can terminate outbreaks, however, if the insect has not developed cold-hardiness. Temperatures of −15° F under the bark will kill nearly all adults, while −30° F will kill the larvae (Schmid and Beckwith 1971).

Certain chemicals are effective in killing spruce beetles; but chemical control is expensive and only a temporary measure until potentially susceptible trees can be removed (Schmid and Frye 1977). In infested stands, or those with potential beetle problems, felling and salvaging attacked or susceptible trees, and disposing of green cull material is the most effective silvicultural control in old-growth stands. The buildup of spruce beetle populations in logging residue can be minimized by cutting to low stump heights, limbing cull logs and tops then cutting them into short lengths and scattering them where they will be exposed to the sun (Schmid 1977). Partial cutting that removes the larger overmature trees and releases the younger trees is another way to reduce potential insect problems in stands with a good stocking of trees in the smaller diameter classes. "Trap trees" intentionally felled prior to beetle flight are highly attractive, and often provide an effective way of concentrating and trapping spruce beetles (Nagel et al. 1957). In static infestations, a ratio of 1 trap tree for every 10 standing infested trees is recommended. This ratio should be 1:2 for increasing infestations (Schmid and Frye 1977). After the beetles enter, the downed logs are usually salvaged, but may be chemically treated or burned (Schmid and Beckwith 1971). Lethal traps, in which cacodylic acid is used to prevent brood development in trap trees, appear to be a potentially useful refinement to the regular trap-tree approach (Buffam et al. 1973). As old-growth is converted to managed stands of second-growth, control of stand density and maintenance of vigor may be an effective silvicultural control.

The western spruce budworm (*Choristoneura occidentalis* Freeman) is another potentially destructive insect attacking Engelmann spruce and subalpine fir (Furniss and Carolin 1977, Whiteside and Carolin 1961). Budworm populations have been contained by combinations of several natural control factors—parasites, predators, diseases, and adverse climatic conditions.

Subalpine fir is attacked by several groups of insects (Keen 1952), the most important of which is the fir engraver (*Scolytus ventralis* LeConte) (Stevens 1971). The western balsam bark beetle (*Dryocoetes confusus* Swaine) may at times be very destructive locally (Furniss and Carolin 1977).

DISEASES

The most common diseases in spruce-fir stands are caused by wood-rotting fungi that result in loss of volume (Hinds 1977, Hinds and Hawksworth 1966, Hornibrook 1950) and predispose trees to windthrow and windbreak (Alexander 1964, 1967). Studies of cull indicators and associated decay in Colorado indicated that stand defect caused by wood rotting fungi in mature to overmature Engelmann spruce ranges from 7% to 26% of the gross volume (Hinds 1977). Trunk rots which cause from 75% to 90% of the decay are associated with *Phellinus pini* (Thore ex Fr.) Karst (= *Fomes pini* (Fr.) Karst), *Haematosterceum sanguinolenta* (Aib. ex Schw. ex Fr.) Pouz. (= *Stereum sanguinolentum* (Alb. and Schw. ex Fr.) Fr.), *Echinodontium sulcatum* (Bart.) Gross (= *Stereum*

sulcatum Bart.) and *Amylosterceum chailletii* (Pers. ex Fr.) Boid (= *Stereum chailletii* (Pers. ex Fr.) Fr.). Major root and butt fungi are *Phellinus nigrolimitalus* (Rohm.) Bourd. et Galz. (= *Fomes nigrolimitatus* (Rom.) Engel.), *Flammula alnicola* (Fr.) Kummer (= *Pholiota alnicola* (Fr.) Sanger), *Polyporus tomentosus* var. *circinatus* (Fr.) Sartory et Maire, *Gloeocystidiellum radiosum* (Fr.) Boid (= *Corticum radiosum* (Fr.) Fr.) and *Coniophora puteana* (Schum ex. Fr.) (Hinds 1977, Hinds and Hawksworth 1966). Most basal decay is associated with old basal wounds and frost cracks. Hinds and Hawksworth (1966) provided a means of estimating defect in standing spruce based on the average amount of cull associated with specific indicators.

Decay in relation to age, diameter, and site quality has been determined for subalpine fir in Colorado (Hinds 1977, Hinds et al. 1960). Stand defect in subalpine fir ranges from less than 7% of the volume in trees less than 10 inches d.b.h. to more than 40% in trees larger than 20 inches d.b.h. Trunk rots which account for about 60% to 70% of the total defect include *Haematosterceum sanguinolenta*, *Phellinus pini*, and *Amylosterceum chailletii*. These decay organisms enter the tree mainly through wounds or broken branches. Major root and butt fungi are *Gloecystidiellum radiosum*, *Coniophora puteana*, *Armillaria mellea* (Vahl. ex Fr.) Quel., *Coniophorella olivacea* (Fr.) Karst (= *Coniophora olivacea* (Fr.) Karst.), *Polyporus tomentosus* var. *circinatus*, and *Philiota squarrosa* (Fr.) Kummer).

As old-growth is converted to managed stands, heart rots can be expected to decrease. Early removal of spruce with known indicators of rot, and of fir in the older age classes will aid in establishing healthy, vigorous forests with a greater growth potential. Rot losses in future stands can be minimized by shorter cutting rotations—140 to 160 years for spruce, and 100 to 120 years for fir. Careful marking of individual trees to be cut and close supervision of logging operations to reduce mechanical injuries minimize points of entry for decay fungi. Proper slash disposal lowers the inoculum potential of heart rot fungi in residual stands. These sanitation methods are important, because direct control of heart rots is not yet possible (Hinds 1977).

Spruce broom rust (*Chrysomyxa arctostaphyli* Diet.) and fir broom rust (*Melampsorella caryophyllacearum* Schroet.) also are common in spruce-fir forests. They cause bole deformation, loss of volume, spiketops, and windbreak, and provide infection courts for decay fungi (Peterson 1963). Conversion of old-growth to younger vigorous stands and sanitation cutting are the only practical means of reducing rust infections.

Dwarf mistletoe (*Arceuthobium microcarpum* (Engelm.) Hawksworth and Weins) attacks spruce over a limited range in the Southwest (Hawksworth and Weins 1972). It causes top-dieback, defects, provides courts of entry for other diseases and insects, reduces seed production, reduces growth and vigor, and may cause severe mortality. The largest spruce trees in residual overstories are the most heavily infected, and are the source of infection for younger trees. Infection is greater in understory trees with an overstory of older infected trees than in stands without an overstory. While drawf mistletoe infection is heaviest in older and larger trees, all classes are susceptible, even seedlings.

Both subalpine and corkbark firs occasionally are parasitized by dwarf mistletoes whose primary hosts are white fir or Douglas-fir; but these attacks usually are not damaging (Mathiasen and Hawksworth 1983). Separation of the old and new stands by clearcutting and felling unmerchantable residual trees appears to be the best way to control dwarf mistletoe. In areas of high tree values, such as recreational, administrative, and home sites, infected branches can be pruned from lightly infected trees; but heavily infected trees must be cut. Partial cutting and thinning generally create ideal conditions for maximum infection and should be avoided where possible, unless the infection is light.

FIRE

Historically, wildfires have burned over large areas where spruce-fir forests grow today. Thin bark, the persistence of dead lower limbs and shallow root systems make spruce and fir susceptible to destruction or severe injury by fire. Moreover, fire damage to the roots and boles predisposes spruce and fir to windthrow and windbreak. However, because of the moist environments where spruce and fir grow, the risk of fire is less than in warmer climates, and relatively few acres have burned in the last 300 to 400 years (Alexander and Shepperd 1984). When severe wildfires do occur, spruce-fir forests may be converted to grass and other low vegetation cover that will persist for considerable time.

ANIMALS

Animals rarely damage established spruce and fir trees. Mule deer (*Odocoileus hemionus* Rafinesque) and elk (*Cervus elaphus* L.), when yarded up in the winter, may browse fir and spruce to some extent. While fir is more palatable than spruce, both species are likely to be taken only as a last resort. Moreover, the spruce-fir type occurs in areas of heavy snowpack not suitable for winter range. Bears (*Ursus* spp.) and porcupines (*Erethizon dorsatum* Brandt) occur in spruce-fir forests but seldom damage these trees.

CUTTING HISTORY

Limited areas of the original spruce-fir forests were logged in the late 1800s to provide fuel, lumber, and timbers for early mining camps. Although cutting on the national forests dates back more than 70 years, only relatively small quantities of timber were harvested until the 1950s. Cutting has accelerated rapidly since then.

Most cuttings in spruce-fir forests before 1950 in the central and southern Rocky Mountains could be collectively called "partial cuttings." They ranged from removal of a few individual trees to removal of all the larger, more valuable trees in the stand. Seedbed prepara-

tion usually was limited to the disturbance created by logging, and slash was untreated or lopped. Most skidding was done with horses.

In general, heavy partial cutting—usually considered necessary to make logging profitable—was not a successful means of arresting stand deterioration or increasing net increment on residual trees, even though most of these cuttings successfully regenerated a new stand. For example, residual stands of spruce-fir in Colorado suffered heavy mortality when 60% of the original volume was removed in the first cut of a two-cut shelterwood (Alexander 1956, 1963) (fig. 6). Net increment was only about one-third of that in uncut stands. Similar results followed heavy partial cutting elsewhere in the central Rocky Mountains (USDA Forest Service 1933), and in the northern Rockies (Roe and DeJarnette 1965). Even when mortality was not a problem, heavy partial cutting left the older, decadent stands in a shabby condition, with little appearance of permanent forest cover.

Windfall, the principal cause of mortality, increased as the intensity of cutting increased. Low stumpage values and the generally scattered pattern of windfall usually prevented salvage of blowdown after partial cutting. Not only was the volume of windthrown trees lost, but the combination of downed spruce and overstory shade provided breeding grounds for spruce beetles.

Partial cutting was successful—in that the residual stand did not suffer heavy mortality and stands were regenerated—in some spruce-fir stands where large reserve volumes were left in protected locations. In one study in northern Idaho, windfall losses were light after a partial cutting that left a residual stand of 6,000 board feet (fbm) per acre in a sheltered location on deep, well drained soil (Roe and DeJarnette 1965). On the Grand Mesa National Forest in Colorado, where spruce trees are relatively short and there are no serious wind problems associated with topography, few trees blew down when about 40% of the original volume was removed from two-storied stands. In single-storied stands, however, only about 30% of the original volume could be safely removed. In contrast, heavier partial cutting that removed 50% or more of the original volume per acre from spruce-fir forests in the dry "rain shadow" of the Continental Divide on the Rio Grande National Forest did not result in blowdown to the residual stand. However, these two-storied stands were growing on sites where productivity was very low. Individual trees were short, widely spaced, and, therefore, relatively windfirm before cutting.

There are also numerous examples of early cuttings—between 1910 and 1930—on many national forests in Colorado, where very light partial cutting—removal of 10% to 15% of the stand—did not result in substantial windthrow of residual trees. Although an overstory tends to favor fir reproduction over spruce, regeneration success of spruce has been acceptable under a wide variety of partial cutting treatments (Alexander 1963, Roe and DeJarnette 1965).

In the early 1950s harvesting shifted to clearcutting. The first clearcuttings were in narrow strips (200 to 400 feet wide) (fig. 7) or small patches or groups that sim-

Figure 6.—Two-cut shelterwood that initially removed 60% of the volume in a spruce-fir stand, Fraser Experimental Forest.

Figure 7.—Clearcutting that removed 50% of the volume in alternate strips in a spruce-fir stand, Fraser Experimental Forest.

Figure 8.—Group selection that removed 50% of the volume in a spruce-fir stand in openings on one-third of the area about one tree height in diameter, Fraser Experimental Forest.

ulated group selection cutting (fig. 8) with little seedbed preparation or slash disposal. Advanced regeneration was not completely destroyed. In general, windfall losses were less than after heavy partial cutting, and the cutovers usually were adequately restocked with a combination of surviving advanced and new reproduction (Alexander 1956, 1957, 1963, 1966, 1968). By the late 1950s, the common practice was to clearcut in large blocks, patches, or wide strips. These larger openings were justified as being more effective in controlling spruce beetles and in reducing logging costs. Slash and cull material were either broadcast burned, bulldozer piled, or windrowed and burned. Hazards from fire and insects were reduced; but removal of all slash, cull material, and residual trees left the seedbeds devoid of shade, thereby creating a difficult microenvironment for the establishment of either natural or artificial regeneration (Roe et al. 1970, Ronco 1970). Furthermore, the destruction of advanced reproduction usually was an unnecessary loss of valuable growing stock.

In the 1970s, after nearly 20 years of harvesting spruce-fir almost exclusively by clearcutting, there was a shift in cutting practices to either some form of partial cutting, usually shelterwood, or a combination of partial cutting and small cleared openings without complete cleanup of slash and other logging debris (Alexander 1973). This shift was necessary because clearcutting large areas often (1) resulted in adverse visual and environmental impacts, (2) was incompatible with the objectives of other forest uses, and (3) led to regeneration failures. Today, spruce-fir forests are harvested by a variety of cutting methods (Alexander 1977, Alexander and Engelby 1983).

REGENERATION SILVICULTURAL SYSTEMS

Both even- and uneven-aged silvicultural systems can be used to regenerate spruce and fir. The forests can be harvested by clearcutting, shelterwood, and selection cutting, and by modifications of these methods. The seed-tree cutting method is not a suitable method of regenerating spruce-fir stands because of susceptibility to windfall (Alexander 1977, Alexander and Engelby 1983). The objective of each regeneration system is to harvest the timber crop and obtain adequate reproduction. The choice of cutting method depends on management objectives and environmental considerations; but stand conditions, associated vegetation, and windfall and spruce beetle susceptibility that vary from place to place on any area, impose limitations on how individual stands can be handled. Cutting to bring old-growth under management is likely to be a compromise, therefore, between what is desirable and what is possible. Management on many areas may involve a combination of several partial cutting treatments, clearcutting, and sanitation salvage cutting (Alexander 1973, 1974, 1977).

EVEN-AGED CUTTING METHODS

Even-aged cutting methods—clearcutting and shelterwood—have been used almost exclusively in spruce-fir stands since the mid-1950s because of several factors.

Spruce and fir, although fairly shade-tolerant, frequently do not have the age-class structure normally associated with shade-tolerant species. They often tend to be even-aged or even-sized rather than all-aged (LeBarron and Jemison 1953).

Many spruce-fir stands are overmature. One way to bring these stands under management is to harvest the old-growth, either in one operation or over a short period of time, and replace it with a new stand.

Heavy partial cutting or clearcutting generally reduces the cost of logging, because fixed costs are spread over a greater volume of timber removed.

Frequent entry with light cuts favor the more shade-tolerant and less valuable firs. These species are especially vulnerable to logging damage and subsequent decay.

Management with Advanced Regeneration

Simulated Shelterwood Cutting

This cutting method removes the overstory from a manageable stand of advanced reproduction in one or more operations (fig. 9). It simulates the final harvest of a standard shelterwood. This option can be used in stands where trees are either uniformly spaced or where they are clumpy, groupy, or patchy.

Although many spruce-fir forests have an understory of advanced growth, and these trees will respond to release after cutting, wide variations in age, composition, quality, and quantity of advanced reproduction require careful, precutting evaluation of the potential for future management. This evaluation should include site quality and habitat type. One course of action is followed if the advanced reproduction is to be managed, another if a manageable stand is not present, cannot be saved, is not expected to grow well, or the manager chooses to destroy it and start over (Roe et al. 1970).

Prelogging evaluation.—The initial examination must answer the following questions: (1) How much of the area is stocked with acceptable seedlings and saplings, and will that stocking insure a satisfactory replacement

Figure 9.—Simulated shelterwood in an old-growth spruce-fir stand, Fraser Experimental Forest.

stand? (2) Can it be logged economically by methods that will save advanced reproduction? Is the timber volume too heavy to save advanced reproduction if it is removed in one cut? (3) How much of the area will require subsequent natural or artificial regeneration, either because advanced reproduction is not present or will be damaged or destroyed in logging?

Because any kind of cutting is likely to destroy or damage at least 50% of the advanced growth, a manageable stand of advanced reproduction before cutting should contain at least 600 acceptable seedlings and saplings per acre, at least 50% of which should be spruce. There are few data available on the growth response of advanced reproduction after release in the central and southern Rocky Mountains; but in the Intermountain Region, McCaughey and Schmidt (1982) found that both advanced spruce and fir regeneration made good height growth after clearcutting and partial cutting. The following criteria, therefore, are based largely on experience and observations. To be acceptable, reproduction must be of good form, able to make vigorous growth when released, and be free of defect or mechanical injury that cannot be outgrown. Trees larger than 4 inches d.b.h. may be acceptable; but they should not be included in the prelogging regeneration survey, because they are more likely to be damaged or destroyed in logging, or windthrown after logging. Stands or portions of stands not meeting these criteria have to be restocked with subsequent natural or artificial regeneration (Roe et al. 1970).

Cutting and slash disposal treatment.—Mature and overmature trees should be cut to release advanced reproduction and harvest merchantable volume. Seed sources need not be reserved from cutting unless required for fill-in stocking. The size, shape, and arrangement of units cut is not critical for regeneration; but to be compatible with other key uses, they should be no wider than about five to eight times tree height, should be irregular in shape, and blend into the landscape. Not more than one-third of any drainage or working circle should be cut over at any one time.

Protection of advanced reproduction begins with a well-designed logging plan (Roe et al. 1970). Logging equipment and activity must be suited to the terrain and rigidly controlled to minimize damage to advanced reproduction and disturbance to soil. Skid roads should be located at least 200 feet apart and marked on the ground before cutting. Skidding equipment should be moved only on skid roads. Where possible, trees should be felled into openings at a herringbone angle to the skid road to reduce disturbance when logs are moved onto the skid road (Alexander 1957, Alexander 1974, Roe et al. 1970). It may be necessary to deviate from a herringbone felling angle in order to drop the trees into openings. In this case, the logs will have to be bucked into short lengths to reduce skidding damage. Furthermore, the felling and skidding operations must be closely coordinated, because it may be necessary to fell and skid one tree before another is felled. Dead sound material and snags that are felled should be skidded out of the area to minimize the amount of slash and unmerchantable material. In stands with heavy volumes per acre, it may be necessary to remove the overstory in more than one cut (Alexander 1974).

Slash treatment then should be confined to areas of heavy concentrations as required for protection from fire and insects or preservation of esthetic values (Roe et al. 1970). Slash also must be treated carefully to avoid damage to advanced reproduction. If trees are felled into openings as much as possible, a minimum of turning and travel with brush dozers will be needed to concentrate the slash for burning. Slash piles should confine burning to the smallest area possible.

Postlogging reevaluation.—Even with careful logging and slash treatment, some advanced reproduction will be damaged or destroyed. The area must be surveyed to: (1) Determine the extent of damage to the reproduction. At least 300 acceptable seedlings and saplings per acre, of which at least 50% should be spruce, must have survived to consider the area adequately stocked. This is in addition to any trees larger than 4 inches d.b.h. that survived. Areas that do not meet these standards need fill-in or supplemental stocking. (2) Plan stand improvement—cleaning, weeding, and thinning—to release crop trees. Cutover areas should not be considered in an adequate growing condition until the crop trees are free to grow and the necessary fill-in planting or natural regeneration is complete (Roe et al. 1970). It is especially important to fell larger reproduction that has been broken off or sustained basal wounds. These trees can occupy significant areas and eventually become culls because of decay.

Management for Regeneration After Cutting

Clearcutting

This method harvests the timber crop in one step to establish a new stand. Because a large proportion of the spruce-fir type is in overmature sawtimber stands that have little potential for future management because of their advanced age, relatively slow growth, and susceptibility to wind and insects, forest managers concerned with timber production have usually decided to convert old-growth to managed stands by clearcutting in strips, patches, and blocks (fig. 10). Therefore, harvesting and regeneration practices developed in the central Rocky Mountains have been directed toward this objective. Much of the criticism of past clearcutting operations in spruce-fir can be attributed in part to poor cutting practices, particularly where large openings were cut, geometric patterns that did not complement the landscape were used, unsightly logging debris was left on the ground, and areas were not regenerated. However, from a silvicultural point of view, clearcutting, properly done, is still an acceptable harvesting method in spruce-fir forests (Alexander 1974, 1977, Alexander and Engelby 1983).

Cutting unit layout, logging plans, slash disposal, and seedbed treatment should be designed to (1) facilitate seed dispersal, (2) promote seedling survival and establishment, and (3) create favorable growing conditions.

If natural regeneration fails, plans must be made to use artificial regeneration (Roe et al. 1970). Clearcutting can be readily adapted to multiple use land management by judicious selection of size, shape, and arrangement of openings in combination with other high-forest cutting practices (Alexander 1974, 1977).

Size of cutting unit.—Requirements for seed dispersal and site preparation will influence the size of opening that will restock naturally (Roe et al. 1970). The cutting unit must be designed so that seed from the surrounding timber margin reaches all parts of the opening, unless supplementary artificial regeneration is planned. Effective seeding distance and aspect determine the size of opening.

The tabulations that follow are guides developed for the central Rocky Mountains. They are based on 20 years of seed production and dispersal data from six areas in Colorado (Alexander 1969, Alexander and Edminster 1983, Alexander et al. 1982, Noble and Ronco 1978), and 15 years of spruce survival data from the Fraser Experimental Forest in Colorado in an *Abies lasiocarpa/Vaccinium scoparium* habitat type (Alexander 1983, 1984). Effective seeding distance, as used here, is defined as the distance to which sufficient sound seed is dispersed to provide 800 5-year-old seedlings—a desirable stocking goal for Engelmann spruce (Alexander and Edminster 1980)—on (1) mineral soil seedbeds where competition from competing vegetation has been eliminated, and 50% overhead shade and protection from rodents has been provided; (2) on unshaded mineral soil seedbeds where competing vegetation has been removed and protection from rodents has been provided; (3) natural seedbeds with 50% overhead shade and protection from rodents provided; and (4) natural unshaded seedbeds with only protection from rodents provided.

The number of 5-year-old seedlings expected to become established on two aspects in relation to the number of sound seeds is as follows.

Seedbed and aspect	Seedlings per 1,000 sound seeds
Shaded mineral soil	
North	31
South	3
Unshaded mineral soil	
North	13
South	0
Shaded, natural	
North	14
South	3
Unshaded, natural	
North	2
South	0

The estimated maximum distance that can be seeded from all sides and maximum size of opening that can be restocked in 5 years on two aspects, based on an accumulative 5-year seed production of 500,000 sound seeds per acre, is as follows (Alexander 1983, 1984; Alexander and Edminster 1983, Alexander et al. 1982).

Figure 10.—Clearcutting in small patches in an old-growth spruce-fir stand, Fraser Experimental Forest.

Seedbed and aspect	Maximum distance that can be seeded (feet)	Maximum size opening (tree heights)
Shaded, mineral soil		
North	400–450	5–6
South	50–100	1–1.5
Unshaded, mineral soil		
North	300–350	4–5
South	0	0
Shaded, natural		
North	300–350	4–5
South	50–100	1–1.5
Unshaded, natural		
North	0	0
South	0	0

Based on these seeding distances, four conclusions can be drawn.

1. Clearcutting with natural regeneration is most likely to succeed on north and east aspects, if the right combination of mineral soil and shade has been created. Even then, more than one good seed year will likely be required to obtain adequate restocking.
2. Clearcutting on south and west aspects is not likely to result in an acceptable stand of new reproduction in a reasonable period of time, even with favorable seedbed and environmental conditions, without fill-in planting to bring reproduction to the minimum acceptable standard.
3. Where larger openings than shown are cut on north and east aspects, it will be necessary to plant the area beyond the effective seeding distance.
4. Where the seed source is of poor quality, plan to plant the cutovers.

Similar guides developed for Intermountain Region conditions by Roe et al. (1970) suggest that openings larger than those indicated here (up to 660 feet, or about 8 times tree height) can be restocked on north aspects if the seed source contains 200 or more square feet of basal area in spruce trees 10 inches d.b.h. and larger; but openings of only 200 to 400 feet wide are likely to restock on south aspects. Effective seeding distance

with a light seed source (70 square feet of basal area or less) will vary from 0 to 200 feet on north aspects and be 0 on other aspects.

Windfall.—The following guidelines for minimizing windfall around the perimeter of clearcut openings were developed in Colorado (Alexander 1964, 1967, 1974).

1. Protection from wind for the vulnerable leeward boundaries is most important.
2. Do not locate cutting boundaries where they will be exposed to accelerated winds funneling through saddles in ridges to the south and west of the cutover area, especially if the ridges are at high elevations (fig. 4).
3. Avoid locating cutting boundaries on ridges or directly below saddles in ridges (fig. 11), especially ridgetops of secondary drainages to the lee and at right angles to the main drainage when the latter is a narrowing valley with steep slopes. One cutting unit should straddle each ridgetop and extend downslope in both directions for a distance of at least 200 feet. That unit may be cut or uncut. Such an arrangement will avoid leaving a cutting boundary on the top of a ridge (fig. 12).
4. Where topography, soils, and stand conditions permit, lay out each unit so that the maximum amount of cutting boundary is parallel to the contour or along a road (fig. 13).
5. Do not lay out cutting units with dangerous wind-catching indentations (fig. 14) or long, straight lines and square corners in the leeward boundary or in boundaries that are parallel to storm winds. V- or U-shaped identations in the boundary can funnel wind into the reserve stand. Long, straight cutting boundary lines and square corners also deflect the wind and cause increased velocities where the deflected currents converge like a windstream flowing over a crest. Irregular cutting boundaries without sharp identations or square corners lessen the opportunity for deflection and funneling of air currents.
6. Do not locate boundaries on poorly drained or shallow soils. Trees grown under these conditions are shallow rooted and susceptible to windthrow.
7. Locate cutting boundaries in stands of sound trees. Trees with decayed roots and boles or root systems that were cut or torn during road building or log skidding operations are poor windfall risks.
8. Locate cutting boundaries in immature stands when possible. Stands of young trees usually are less easily uprooted by strong winds.
9. Locate cutting boundaries in poorly stocked stands. Open-grown trees are more windfirm than trees grown in dense stands.
10. Avoid locating cutting boundaries in areas where there is evidence of old prelogging blowdowns.
11. Reduce blowdown in areas with exceptionally hazardous windfall potential by locating the vulnerable leeward boundaries where hazards are below average, or by eliminating those boundaries by progressive cutting into the wind.

Figure 11.—Clearcut opening directly below a saddle where wind vortexing can occur and increase blowdown risk.

Figure 12.—Clearcut unit boundary on a ridgetop where risk of blowdown is increased.

Figure 13.—Clearcut unit boundaries laid out across the slope that expose the short dimensions of the unit to the wind helps reduce blowdown.

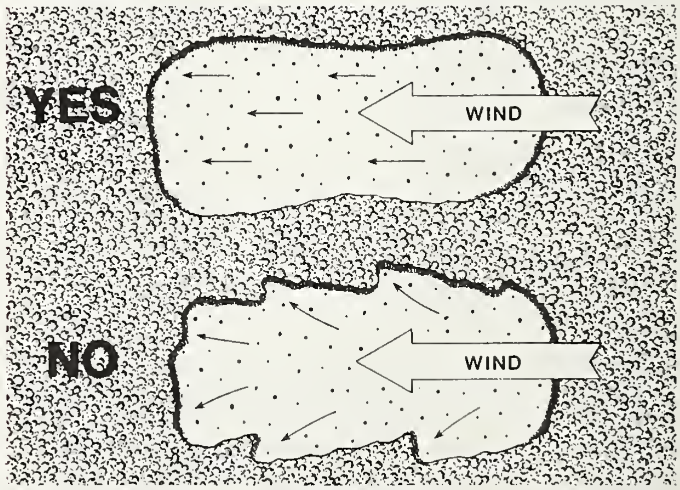

Figure 14.—Irregular cutting boundaries without sharp indentations or square corners help reduce blowdown.

Slash treatment and site preparation.—Slash 8 inches in diameter or larger provides a habitat for spruce beetles; it provides beneficial shade for germination and seedling establishment; in heavy concentrations, it obstructs natural seedling establishment; and it creates an adverse visual impact (Alexander 1974).

Burning slash in large concentrations, such as windrows or piles, often creates enough heat in the soil to inhibit the development of any kind of plant growth for an unknown period of time. Therefore, windrows or piles should be small or narrow, and cover a minimum proportion of the area (Roe et al. 1970).

Mineral soil can be exposed by mechanically scarifying the ground surface, sometimes in connection with slash disposal or by broadcast burning. To be effective, broadcast burning should consume most but not necessarily all of the duff or organic material on the ground, and it should burn hot enough to destroy some or all of the competing vegetation. However, it should not burn so hot that a deep layer of loose ash accumulates, the mineral soil changes color, or the rocks fracture. It must leave cull logs, tops, and other large slash to provide shade and protection for soil and seedlings. Timing of the burn is exceedingly important. The spruce type is generally so cool and moist that times for effective broadcast burning are limited. Burn when the duff is dry enough to be consumed. If only the surface is dry, a blackened organic layer that inhibits seedling establishment will remain (Roe et al. 1970).

Often, logging disturbance alone will be sufficient site preparation, and soil surface conditions should be inspected immediately after logging to determine whether additional site preparation is needed. If so, careful mechanical scarification will prepare a satisfactory seedbed if it exposes mineral soil and destroys some of the competing vegetation, but leaves shade protection. At least 40% of the area should be left as exposed mineral soil. It may be necessary, however, to rearrange some of the residual slash to provide adequate shade. Tractors equipped with brush blades should be used. A complete cleanup job is neither necessary nor desirable for two reasons. First, residual tops and slash shade the seedbed. Second, residual organic material reduces soil erosion. Cut green spruce material larger than 8 inches in diameter should be removed or treated to prevent the buildup of spruce beetle populations; but fir material may be left. On highly erodible soils, the duff layer should be removed along the contour, preferably in strips the width of the dozer blade, with untouched strips intervening. Some of the larger debris then may be pushed back on the scarified strips for protection from erosion, and the dozer may be walked over it at right angles to the strips to break it down (Alexander 1974, Roe et al. 1970).

Shelterwood Cutting

This regeneration cutting method harvests a timber stand in a series of cuts. In a standard shelterwood, the new stand regenerates under the shade of a partial overstory canopy. The final harvest removes the shelterwood and permits a new stand to develop in the opening. In a group shelterwood (a modification of the shelterwood method), the new stand regenerates in small openings that leave standing trees around the margins as a seed source. Openings are too small (2 acres or less) to be classified as a clearcut (U.S. Department of Agriculture 1983). This kind of cutting has been incorrectly called a modified group selection, but differs from a selection cut in the way the growing stock is regulated.

These cutting methods may be the only even-aged options open to the manager where (1) multiple use considerations preclude clearcutting, (2) combinations of small cleared openings and high forests are required to meet the needs of various uses, or (3) areas are difficult to regenerate after clearcutting. However, shelterwood cutting requires careful marking of individual trees or groups of trees to be removed, and close supervision of logging. The following recommendations for shelterwood cutting practices are keyed to broad stand descriptions based largely on experience, windfall risk situations, and insect problems (Alexander 1973, 1974). Practices needed to obtain natural reproduction are also discussed.

Single-storied stands.—Stands may appear to be even-aged (fig. 15), but usually contain more than one age class. Canopy may not appear to be of a uniform height because of changes in topography, stand density, or stocking. Codominant trees form the general level of the overstory canopy. Dominants may be 5 to 20 feet above the general canopy level. Taller intermediates extend into the general canopy; shorter intermediates are below the general canopy level but do not form a second story. Range in diameters and crown length of dominants and codominants is small.

Figure 15.—A single-storied spruce-fir stand.

There are few coarse-limbed trees in the stand; if two-aged or more, younger trees usually have finer branches and smaller diameters than the older trees. Trees are more often uniformly spaced than clumpy. There usually is not a manageable stand of advanced reproduction. Lodgepole pine is absent or sparse.

These stands usually are the least windfirm because trees have developed together over a long period of time and mutually protect each other from the wind.

If windfall risk is low, and trees are uniformly spaced, the first cut should remove about 30% of the basal area of the stand on an individual tree basis (fig. 16). It resembles the preparatory cut of a three-step shelterwood. Because all overstory trees are about equally susceptible to windthrow, the general level of the canopy should be maintained by removing some trees from each crown class. Those trees with known indicators of defect should be removed first; but avoid creating openings in

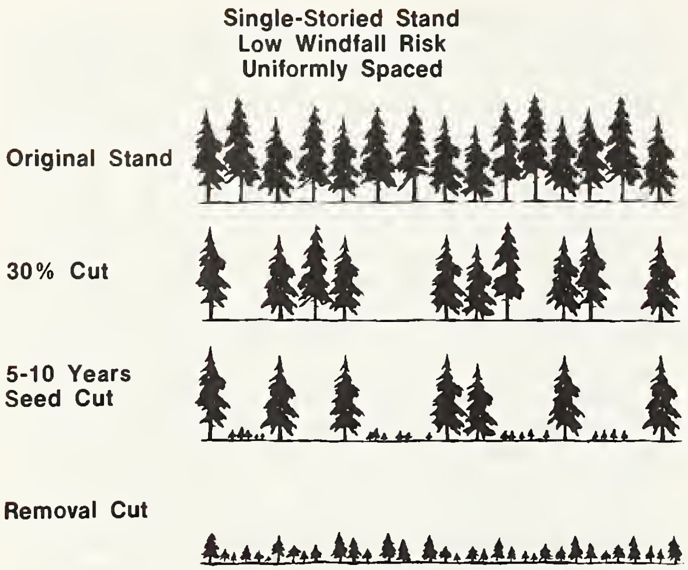

Figure 16.—Sequence of entries with a 3-cut shelterwood in a uniformly-spaced, single-storied spruce-fir stand in a low windfall risk situation.

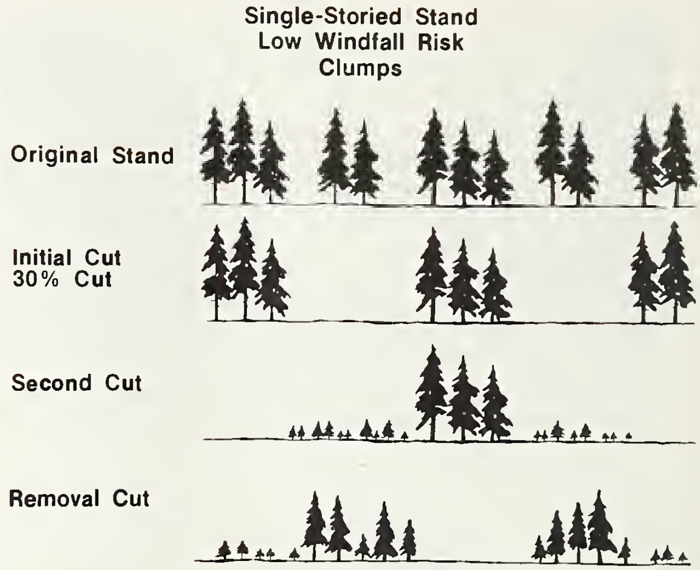

Figure 17.—Sequence of entries with group shelterwood in a clumpy-spaced, single-storied spruce-fir stand in a low wind risk situation.

the canopy with a diameter larger than one tree height by distributing the cut over the entire area. Do not remove dominant trees in the interior of the stand that are protecting other trees to their leeward if these latter trees are to be reserved for the next cut. In these, and all other stands described with natural openings of one to several acres, leave the trees around the perimeter for a distance of about one tree height until the final entry. These trees have been exposed to the wind and are usually windfirm, and protect the trees in the interior of the stand.

The second entry into the stand should be delayed for 5 to 10 years after the first cut in order to determine if the residual stand is windfirm. This cut should also remove about 30% of the original basal area on an individual tree basis. It simulates the seed cut of a three-step shelterwood. The largest and most vigorous dominants and codominants should be reserved as a seed source; but avoid cutting openings in the canopy larger than one tree height in diameter by distributing the cut over the entire area, even if it means leaving trees with poor seed production potential.

The last entry into these uniformly-spaced stands is the final harvest, which should remove all of the remaining original overstory. It should not be made until a manageable stand of reproduction has become established; but the cut should not be delayed beyond this point if timber production is one of the primary concerns, because the overwood hampers the later growth of seedlings.

The manager also has the option of removing less than 30% of the basal area at any entry and making more entries; but they cannot be made more often than every 5 to 10 years. This will spread the cut over time and maintain a continuous forest cover longer.

If windfall risk is low, but trees are clumpy or groupy, the first cut should be a group shelterwood that removes about 30% of the basal area. Harvesting timber in groups will take advantage of the natural arrangement of trees. Openings should be kept small—not more than one or two tree heights in diameter—and not more than one-third of the area should be cut over (fig. 17). All trees in a clump should be either cut or left, because they mutually support each other, and removing only part of a clump is likely to result in windthrow of the remaining trees.

The second entry into the stand should not be made until the first group of openings has regenerated. This cut also removes about 30% of the original basal area without cutting over more than an additional one-third of the area. Openings should be no closer than about one to two tree heights to the openings created by the initial cut.

The final entry into these clumpy or groupy stands should remove the remaining groups of merchantable trees. Timing of this cut depends upon how the manager decides to regenerate the new openings. If it is by natural regeneration, the final harvest must be delayed until the regeneration in the openings cut earlier is large enough to provide a seed source.

In these stands, the manager may again choose to remove less than 30% of the basal area and cut over less than one-third of the area at any one time. This will require more entries; but no new cuttings should be made until the openings cut the previous entry have regenerated. The last groups cannot be cut until there is either a seed source or the manager elects to plant these openings.

If windfall risk is above average (moderate), and trees are uniformly spaced, there are two alternatives. In Alternative 1 (fig. 18), the first cut should be a very light preparatory cutting that removes about 10% of the basal area on an individual tree basis, to open up the stand while minimizing windfall risk to the residual trees. This cutting resembles a sanitation cut in that the poorest risk trees—those of low vigor and with known indicators of

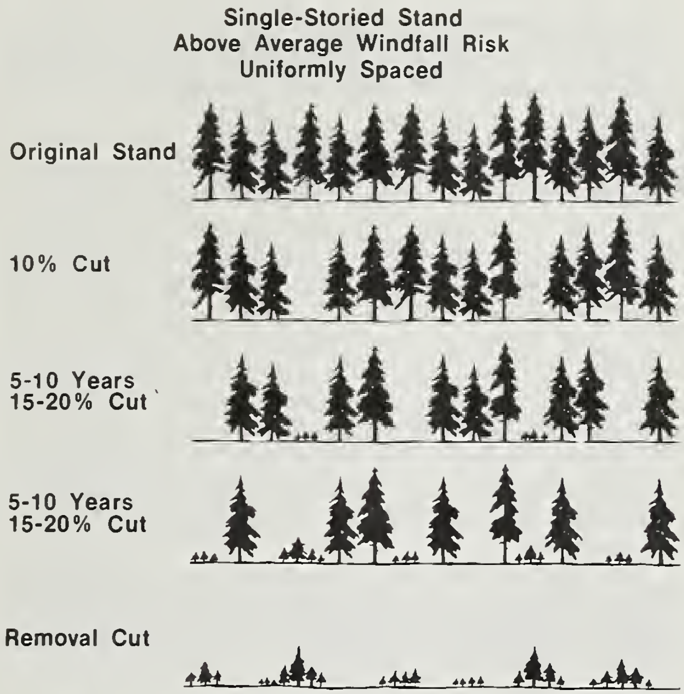

Figure 18.—Sequence of entries for Alternative 1 with a shelterwood in a uniformly-spaced, single-storied spruce-fir stand in an above-average wind risk situation.

defect—and predominants should be removed; but it is important to maintain the general canopy level. Provision should be made to salvage any postharvest windfalls after spruce beetle flight at the end of July.

The second entry can be made about 10 years after the first cut. This entry should remove about 15% to 20% of the original basal area on an individual tree basis. Any windfall salvaged after the first cut should be included in the computation of the basal area to be removed. This preparatory cut is intended to continue opening up the stand gradually preparing for the seed cut. Most of the trees marked for removal should be intermediates and small codominants; but the general canopy level should be maintained.

It will require another 5 to 10 years to determine if the stand is windfirm enough to make another entry. This entry is seed cut, and should remove about 15% to 20% of the basal area, including any windfalls salvaged since the last cutting. The largest and most vigorous dominants and codominants should be reserved as a seed source, but it is also important to distribute the cut over the entire area.

The last entry is the final harvest to remove the remaining overstory. It cannot be made until a manageable stand of reproduction has established. About 50% of the basal area will be removed in this cut. If this volume is more than 10,000 fbm per acre, it is probably too heavy to be removed in one harvest without undue damage to the reproduction. The manager must plan on a two-step final harvest. The second step can begin as soon as the skidding is finished in the first step, provided that a manageable stand of reproduction still exists.

In Alternative 2 (fig. 19) in evenly-spaced stands with moderate windfall risk, the first entry is the same as

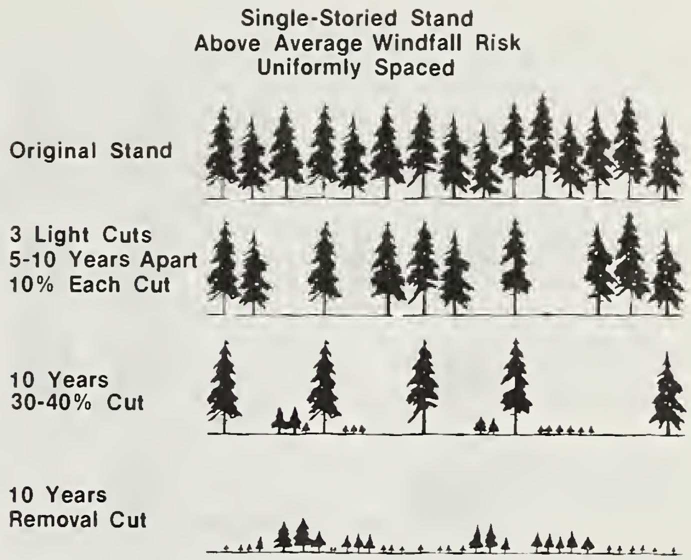

Figure 19.—Sequence of entries for Alternative 2 with a shelterwood in a uniformly-spaced, single-storied spruce-fir stand in an above-average wind risk situation.

under Alternative 1. The second and third entries are made at 5- to 10- year intervals. Each entry removes about 10% of the basal area. The objectives are still to open up the stand, minimize windfall risk, and remove the poorest risk trees.

The fourth entry is the seed cut that will be made about 10 years after the third entry, and remove 30% to 40% of the basal area including any windfall salvaged since the last cutting. The largest and most vigorous dominants and codominants should be left as a seed source; but distribute the cut over the entire area.

The last entry is the final harvest to remove the remaining 30% to 40% of the basal area. It cannot be made until there is a manageable stand of reproduction.

Alternative 2 is somewhat risky, because it increases the chances of blowdown; but it encourages a better stand of reproduction, because the stand is opened up more at the seed cut.

If windfall risk is above average and trees are clumpy, the first cut should be light, removing about 10% to 20% of the basal area in a group shelterwood (fig. 20). Openings should be no larger than one tree height in diameter, and not more than one-fifth of the area should be cut over at any one time. All trees in a clump should be cut or left. In stands with small natural openings—about one tree height in diameter—the openings can be enlarged one tree height by removing clumps of trees to the windward.

Four additional entries into the stand can be made at periodic intervals; but no new entry should be made until the openings cut the previous entry have regenerated. The last groups to be removed should be retained until the original group openings are large enough to provide a seed source or plan on planting the openings created by the last cut. About 20% of the basal area should be removed over about one-fifth of the area at each entry. Group openings should be no larger than one tree height in diameter.

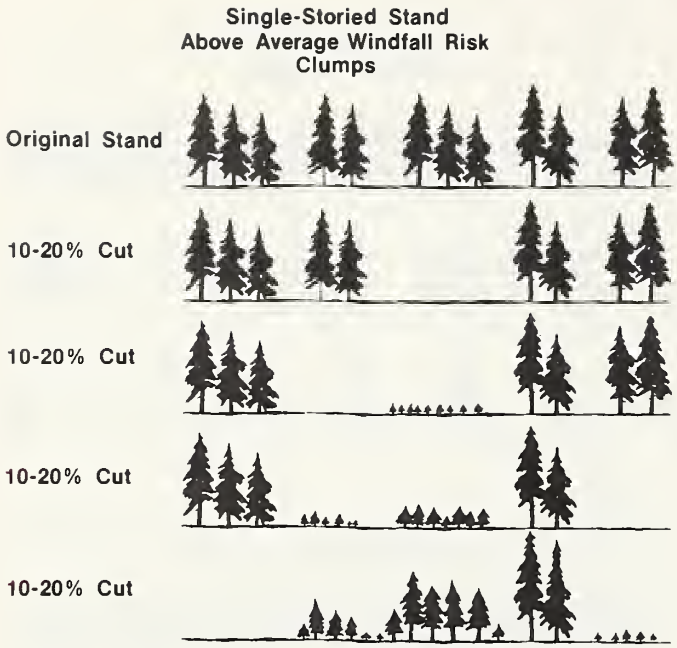

Figure 20.—Sequence of entries with a group shelterwood in a clumpy-spaced, single-storied spruce-fir stand in an above-average wind risk situation.

If windfall risk is very high, the choice is limited to removing all the trees or leaving the area uncut. Cleared openings should not be larger than regeneration requirements dictate, and they should be interspersed with uncut areas of at least equal size. No more than one-third of the total area in this wind risk situation should be cut over at one time.

Two-storied stands.—Stands may appear to be two-aged (fig. 21), but usually contain more than two age classes. Top story (dominants, codominants, and intermediates) is usually spruce, and the stand appears to be single-storied. The second story is often fir; and the trees are younger and smaller in diameter than the overstory. It may consist of small saw logs, poles, or large saplings, but is always below the top story and clearly distinguishable from it. Trees in the second story are overtopped, but not suppressed. There may be a manageable stand of advanced reproduction. Individual trees vary from uniformly spaced to clumpy. Lodgepole pine is absent or sparse.

Recommended cutting treatments are the same as for three-storied stands.

Figure 21.—A two-storied spruce-fir stand.

Three-storied stands.—Stand may appear to be three-aged (fig. 22), but usually contain more than three age classes. Occasionally they are two-aged, but never all-aged.

If the stand is three-aged or more, the top story is predominantly spruce and resembles an open-grown single-storied stand. Second and third stories usually are composed of younger and smaller trees, predominately fir. In a typical stand, the second story will be 10 to 30 feet below the top story, and the third story will be 10 to 30 feet below the second story. Although the second and third stories are overtopped, trees are usually not suppressed. If two-aged, the first two stories are old-growth with spruce in the top story and fir in the second story. The third story will be younger trees, largely fir of smaller diameter. The stand may be a manageable stand of advanced reproduction. It is more often clumpy than uniformly spaced. Lodgepole pine is usually absent or sparse.

Trees in the overstory of two- and three-storied stands usually are more windfirm than those in single-storied stands. The second and third stories are likely to be less windfirm than the top story.

Figure 22.—A three-storied spruce-fir stand.

If windfall risk is low, and trees are uniformly spaced, the first cut removes about 40% of the basal area (fig. 23). This cutting is heavy enough to be the seed cut of a two-step shelterwood; but the marking follows the rules for individual tree selection—mature trees are removed from each story. Because the overstory is likely to be more windfirm, selected dominants and codominants of good vigor and free of defect should be left as a seed source. Avoid cutting holes in the canopy larger than one tree height in diameter by distributing the cut over the entire area. Do not remove dominant trees from the interior of the stand that are protecting other trees to their leeward if these latter trees are to be reserved for the next cut.

The second entry is the final harvest to remove the remaining stand and release the reproduction. It cannot be made until the new stand of reproduction is established. If the residual volume is greater than about 10,000 fbm per acre, the final harvest should be made in two stages ("stage logging") to avoid undue damage to new reproduction. The second stage can begin as soon as the skidding is finished in the first.

If there is a manageable stand of advanced reproduction and the volume is not too heavy, the first cut can be simulated shelterwood that removes the overstory. Otherwise, the first cut should remove 40% of the basal area on an individual tree basis as long as the more wind-

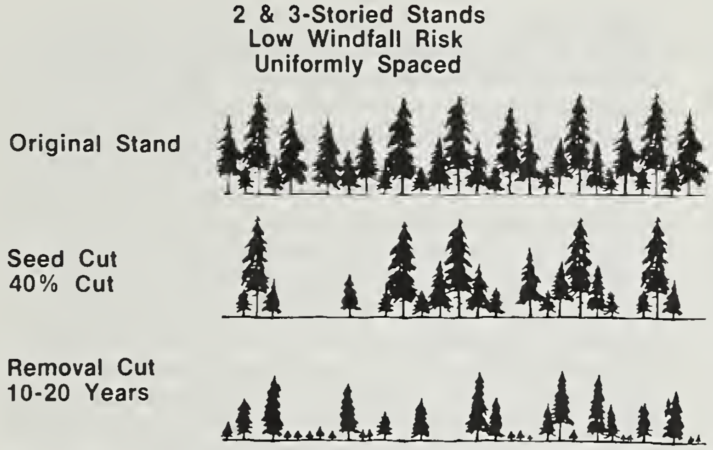

Figure 23.—Sequence of entries with a two-cut shelterwood in a uniformly-spaced, two- or three-storied spruce-fir stand in a low wind risk situation.

firm dominants and codominants are left. The timing of the second cut is not critical from a regeneration standpoint, provided that a manageable stand of reproduction still exists after the first cut.

The manager has other options to choose from, including cutting less than the recommended basal area, making more entries, and spreading the cut out over time by delaying the final harvest until the new stand is tall enough to create a continuous high forest. Another option is to convert these stands to an uneven-aged structure by making a series of light cuts—10% to 20% of the basal area—at frequent intervals—10 to 20 years. Ultimately the stand will contain a series of age classes.

If windfall risk is low, and trees are clumpy (fig. 24), the first cut should remove about 40% of the basal area in a group shelterwood. Openings can be larger (two or three times tree height) than for single-storied stands; but the area cut over should be not more than one-third of the total. Group openings should be irregular in shape, but without dangerous windcatching indentations in the edges. All trees in a clump either should be cut or left.

Two additional entries can be made. They should each remove about 30% of the original basal area in group openings up to two to three times tree height; but not more than one-third of the area should be cut over at any one time. If there is not a manageable stand of advanced reproduction, the manager must wait until the first group of openings is regenerated before cutting the second series. Also, the cutting of the final groups until there is a seed source either must be delayed or these openings must be planted. If there is a manageable stand of advanced reproduction, the timing between cuts is not critical for regeneration.

The manager has the option of removing less than the recommended basal area and cutting less than the recommended area at any one time. This will require more entries and spread the cut over time.

If windfall risk is above average, and trees are uniformly spaced (fig. 25), and if these stands do not contain a manageable stand of reproduction, the first entry should be a preparatory cut that removes up to 20% of the basal area on an individual tree basis. Predominants, intermediates with long dense crowns, and trees with known indicators of defect should be removed first; but the general canopy level should be maintained. The objective of this cut is to open up the stand, and at the same time minimize the windfall risk to remaining trees. Provision should be made to salvage postharvest windfalls after spruce beetle flight in July.

The second entry into the stand should be made in about 10 years. It will remove about 40% of the basal area, including the salvage of any windfalls that occur between the first and second cuts. During this seed cut, the best dominants and codominants should be reserved as a seed source; but it is important to distribute the cut over the entire area.

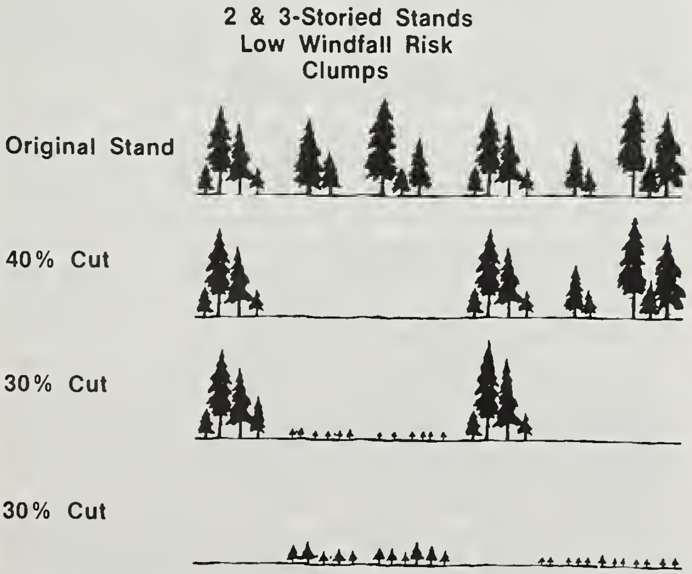

Figure 24.—Sequence of entries with a group shelterwood in a clumpy-spaced, two- or three-storied spruce-fir stand in a low wind risk situation.

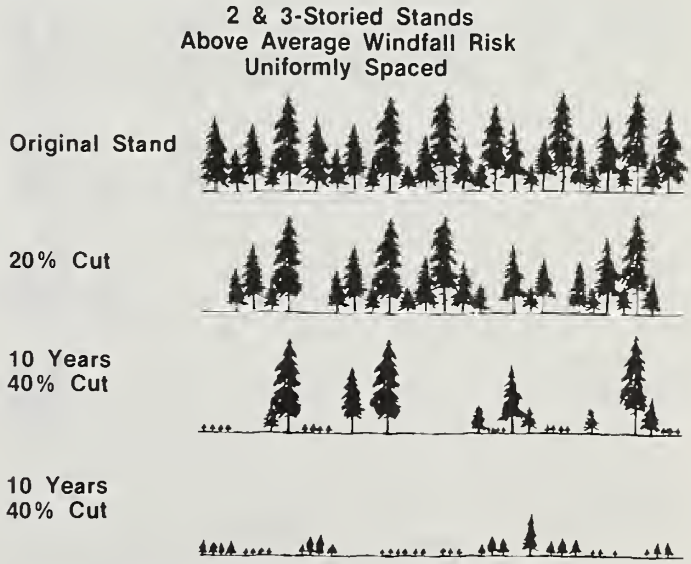

Figure 25.—Sequence of entries with a shelterwood in a uniformly-spaced, two- or three-storied spruce-fir stand in an above-average wind risk situation.

The next entry is the final harvest to remove the remaining merchantable volume and release the reproduction. If the residual stand has too heavy a volume, the final harvest should be made in two steps.

If these stands contain a manageable stand of reproduction and the volume per acre is not too heavy, the first cut can be a simulated shelterwood that removes the overstory. If the volume is too heavy for a one-stage removal, the manager should follow the preceding recommendations, because the wind risk is too great to permit a two-stage removal in a stand that has not been previously opened up.

If windfall risk is above average, and trees are clumpy, the first cut should be a group shelterwood that removes about 25% of the basal area (fig. 26). Openings should be kept small—not more than one or two tree heights in diameter—and not more than one-fourth of the area should be cut over at any one time. All trees in a clump should either be cut or left. Small natural openings can be enlarged one or two tree heights by removing trees in clumps to windward of the opening.

Three additional entries should be made. About 25% of the original basal area should be removed on about one-fourth of the area in each entry. The interval between cuts will depend upon the time required to regenerate each series of openings. The manager must either delay the removal of the final groups until a seed source is available or plant the openings.

If the windfall risks are very high, the choice usually is limited to removing all the trees or leaving the area uncut. Cleared openings should not be larger than regeneration requirements dictate, and should be interspersed with uncut areas. Not more than one-third of the total area in this windfall risk situation should be cut over at any one time.

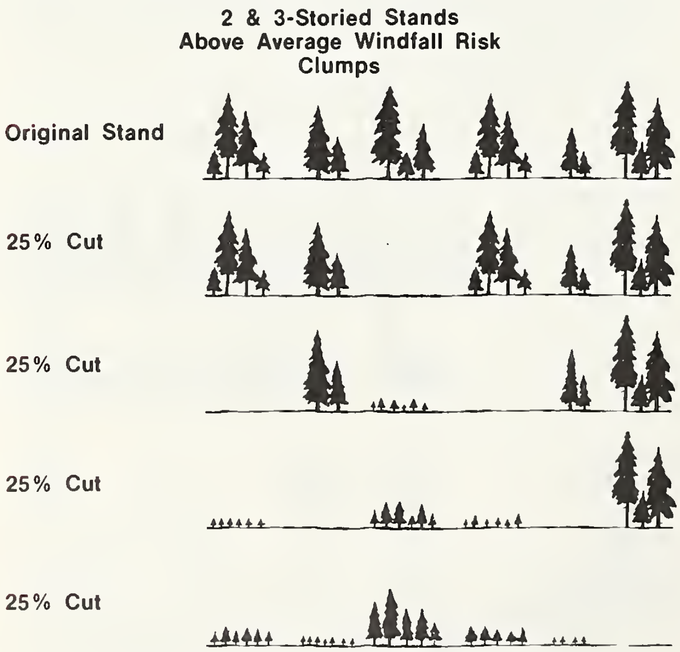

Figure 26.—Sequence of entries with a group shelterwood in a clumpy-spaced, two- or three-storied spruce-fir stand in an above-average wind risk situation.

Multi-storied stands.—These stands are generally uneven-aged (fig. 27) with a wide range in diameters. If the stand developed from relatively few individuals, the overstory trees are coarse limbed, and fill-in trees are finer limbed. Overstory trees may be relatively vigorous. If the stand developed from the deterioration of a single- or two-storied stand, the overstory may be no limbier than fill-in trees. Much of the vigorous growing stock is below saw log size. There is almost always a manageable stand of reproduction. Fill-in trees may be clumpy, but overstory trees are usually uniformly spaced. Lodgepole pine may occur as a scattered component of all stories. These usually are the most windfirm stands, even where they have developed from the deterioration of single- and two-storied stands, because by the time they have reached their present condition the remaining overstory trees are usually windfirm.

Figure 27.—A multi-storied spruce-fir stand.

If windfall risk is low, there is considerable flexibility in harvesting these stands. All size classes can be cut, with emphasis on either the largest or smallest trees in the stand. For example, the first cut can range from removal of all large trees in the overstory to release the younger growing stock, to a thinning from below to improve the spacing of the larger trees (fig. 28). If the manager elects to make a simulated shelterwood that removes the overwood and the volume is too heavy, it should be harvested in two stages. Cutting can then be directed toward either even- or uneven-aged management, with entries made as often as growth and regeneration needs dictate. If the manager elects to make a thinning from below, management of the stand is usually directed toward even-aged management.

If the windfall risk is above average or very high, the safest first cut is a simulated shelterwood that removes the overwood with a thinning from below to obtain a widely spaced, open-grown stand that will be windfirm (fig. 29). Cutting can then be directed toward either even- or uneven-aged management.

Modifications to cutting treatments imposed by spruce beetles.—If spruce beetles are present in the stand at an endemic level, or in adjacent stands in sufficient numbers to make successful attacks, and less than the recommended percentage of basal area to be removed is in susceptible trees, any attacked and all susceptible trees should be removed in the first cut. This will include most of the larger spruce trees and is a calculated risk, especially in above-average wind risk situations. Furthermore, the percentage of fir in the stand will increase. Provision should be made to salvage attacked trees. The remaining cuts should be scheduled in accordance with windfall risk, insect susceptibility, and regeneration needs (Alexander 1974).

If, in these stands, more than the recommended percentage of basal area to be removed is in susceptible trees, the manager has three options: (1) remove all the susceptible trees, (2) remove the recommended basal area in attacked and susceptible trees and accept the risk of future losses, or (3) leave the stand uncut. If the stand is partially cut or left uncut, surviving spruce would probably make up at least 50% of the residual basal area; but most of the merchantable spruce would be small-diameter trees (Alexander 1974).

If the stand is sustaining an infestation that is building up and the manager chooses to either partially cut or leave the stand uncut because clearcutting is unacceptable, there is a risk of an outbreak that will destroy most of the merchantable spruce in the stand and spread to adjacent stands (Alexander 1974).

Cutting to save the residual stand.—In shelterwood cutting, protection of the residual stand from logging damage is a primary concern. The residual stand includes merchantable trees left after standard shelterwood and reproduction established after the seed cut in standard shelterwood, and reproduction established after each cut in group shelterwood. Before the final harvest is made with standard shelterwood, and before each entry with group shelterwood, the manager must determine if there is an acceptable stand of reproduction. Furthermore, the stand must be reevaluated after final harvest in standard shelterwood and after each entry with group shelterwood to determine the need for supplemental stocking. The same criteria used to evaluate advanced reproduction with a simulated shelterwood applies here.

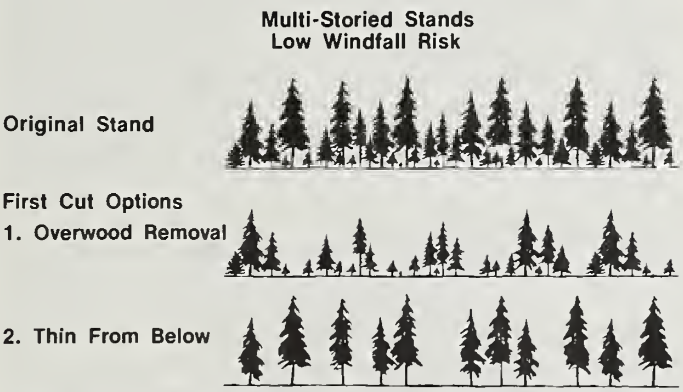

Figure 28.—Options for the first entry into a multistoried spruce-fir stand in a low wind risk situation.

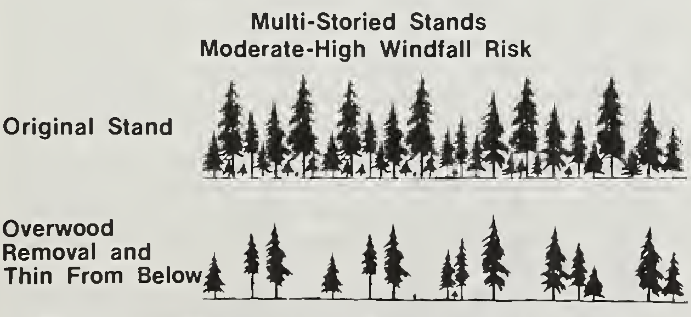

Figure 29.—First entry into a multi-storied spruce-fir stand in an above average to high wind risk situation.

Figure 30.—Schematic drawing of layout of skidroads and felling patterns.

Protection begins with a well-designed logging plan at the time of the first cut. To minimize damage, the same protection measures suggested for simulated shelterwood apply here (fig. 30).

Slash disposal and seedbed preparation.—Some slash disposal probably will be needed after each cut; but it should be confined to concentrations and reduction of visual impact, because most equipment now available for slash disposal is not readily adaptable to working in shelterwood cuttings. Furthermore, burning slash will cause additional damage to the residual stand. Skid out as much of the downed sound dead and green cull material as possible for disposal at the landings or at the mill. Some hand piling or scattering may be needed where slash disposal equipment cannot be used. In group shelterwood cutting, if a manageable stand of reproduction has not been established, dozers equipped with brush blades can be used to concentrate slash for burning in the openings. Piles should be kept small to reduce the amount of heat generated. Leave some of the larger pieces of slash and other debris in place to provide shade for new seedlings. Cut green spruce material larger than 8 inches in diameter should be removed to reduce the buildup of spruce beetle populations (Alexander 1974).

On areas to be regenerated, a partial overstory canopy of trees standing around the margins of small openings provide two of the basic elements necessary for regeneration success—a seed source within effective seeding distance, and an environment compatible with germination, initial survival, and seedling establishment. The manager must make sure that the third element—a suitable seedbed—is provided after the seed cut where standard shelterwood cutting is used, and after each cut where group shelterwood is used. If at least 40% of the available ground surface is not exposed mineral soil after logging and slash disposal, additional seedbed preparation is needed. Until special equipment is developed, the same problem exists as with slash disposal. The equipment currently available is too large to work well around standing trees. Smaller machines equipped with suitable attachments will have to be used (Alexander 1974).

UNEVEN-AGED CUTTING METHODS

Multi- and three-storied spruce-fir stands frequently are uneven- to broad-aged or have the diameter distribution normally associated with uneven-aged stands. Although uneven-aged cutting methods—individual tree and group selection—seldom have been used in spruce-fir forests, they appear to simulate the natural dynamics of these forests. Moreover, uneven-aged management is more compatible or desirable for some management objectives or resource needs. For example, the impact on the forest should be as light as possible in areas of erosive soils, or where management goals include maintenance of continuous high forests. Uneven-aged management often is more appropriate for these conditions and objectives.

Uneven-aged management includes cultural treatments, thinnings, and harvesting necessary to maintain continuous high forest cover, provide for regeneration of desirable species, either continuously or at each harvest, and provide for controlled growth and development of trees through the range of size classes needed for sustained yield of forest products. Managed uneven-aged stands are characterized by trees of many sizes intermingled singly or in groups. Cutting methods do not produce stands of the same age that are large enough to be recognized as a stand. Forests are subdivided into recognizable units that can be located on the ground on the basis of timber type, site, logging requirements, etc., rather than acreage in stand-age classes. Regulation of growing stock is accomplished by setting: (1) a residual stocking goal, in terms of basal area or volume, that must be maintained to provide adequate growth and yield, (2) a diameter distribution goal that will provide for regeneration, growth and development of replacement trees, and (3) a maximum tree size goal. In addition, a decision must be made on how to handle small trees. The procedures described here are for initial entry into unregulated old-growth spruce-fir stands that are to be converted to managed uneven-aged stands using either individual-tree or group selection cutting.

Individual Tree Selection Cutting

This regeneration cutting method harvests trees in several or all diameter classes on an individual basis. Stands regenerate continuously. The ultimate objective is to provide a stand with trees of different sizes and age classes intermingled on the same site (USDA Forest Service 1983). Choice of trees to be cut depends on their characteristics and relationship to stand structure goals set up to regulate the cut. This cutting method provides maximum flexibility in choosing trees to cut or leave, and is appropriate only in uniformly spaced stands with irregular to all-aged structure. Individual-tree selection cutting favors fir over spruce; and in mixed spruce-fir-lodgepole pine stands, few intolerant pines become established after initial cutting (Alexander and Edminster 1977b).

Group Selection Cutting

This regeneration cutting method harvests trees in groups, ranging from a fraction of an acre up to about 2 acres (USDA Forest Service 1983). This cutting method is similar to a group shelterwood except in the way the growing stock is regulated. The area cut is smaller than the minimum feasible for a single stand under even-aged management. Trees are marked on an individual-tree basis; but emphasis is on group characteristics, which means trees with high potential for future growth are removed along with trees with low growth potential. Loss in flexibility is partly offset by the opportunity to uniformly release established regeneration and reduce future logging damage. When groups are composed of only a few trees, the method can be used together with individual-tree selection cutting. This cutting method is most appropriate in irregular to all-aged stands that are clumpy or groupy. However, it can be used in uniformly spaced stands with the size, shape, and arrangement of openings based on factors other than the natural stand conditions (Alexander and Edminster 1977a, 1977b).

Stand Structure Goals

Control of Stocking

The first step in applying a selection cut to a spruce-fir stand is to determine the residual stocking level to be retained. Because total stand growth for many species adapted to uneven-aged management does not differ greatly over the range of stocking levels likely to be management goals, stocking levels set near the lower limit, where no growth is lost, concentrate increment on fewest stems. This reduces time required to grow individual trees to a specific size, and requires a minimum investment in growing stock (Alexander and Edminster 1977b).

The residual stocking level with the best growth in spruce-fir stands varies with species composition, management objectives, productivity, diameter distribution, etc. In unregulated old-growth spruce-fir stands with irregular structure, stocking usually varies from 150 to 300 square feet of basal area per acre in trees in the 4-inch and larger diameter classes (Alexander 1985a, Alexander et al. 1982). Basal areas above 200 square feet per acre probably represent overstocking. While no guidelines are available for uneven-aged stands, residual stocking levels of GSL 100 to GSL 180 are suggested for managed even-aged stands, depending on site productivity, number of entries, and other management objectives (Alexander and Edminster 1980). These levels should be useful in estimating initial residual stocking goals in terms of square feet of basal area per acre for that part of the stand that eventually will be regulated under uneven-aged management (Alexander and Edminster 1977b).

While these general recommendations are probably adequate to start with, use of yield tables for even-aged spruce-fir stands in setting stocking goals for uneven-

aged stands assumes there is little difference between the growing stock of the two, other than a redistribution of age classes over a smaller area (Bond 1952). This may be true when stands without a manageable understory of advanced growth are harvested by a group selection method. The result is likely to be a series of small, even-aged groups represented in the same proportion as a series of age classes in even-aged management. If advanced growth of smaller trees has become established under a canopy of larger trees, however, a different structure may develop with either individual-tree or group selection systems. Growing space occupied by each age or size class is being shared (Reynolds 1954). Assuming that damage to understory trees resulting from removal of part of the overstory trees can be minimized, advanced growth will successfully establish a series of age classes on some areas. In this situation, more trees of a larger size can be grown per acre than with a balanced even-aged growing stock (Bourne 1951, Meyer et al. 1961). Nevertheless, without better information, the residual stocking goals set for even-aged management are the best criteria available.

Maximum Tree Size

The second item of information needed is the maximum diameter of trees to be left after cutting. In old-growth spruce-fir stands, maximum diameter usually varies from 18 to 30 inches d.b.h., depending on stand density, site quality, species composition, etc. Examination of plot inventory information from unmanaged stands with irregular stand structure, suggests that a diameter of 24 inches can be attained within the time period generally considered reasonable under a wide range of site quality and stocking conditions. In the absence of any information on growth rates in uneven-aged stands, or rates of return for specific diameter and stocking classes, a 24-inch maximum diameter seems a reasonable first approximation to set for timber production. Trees of larger diameter with a lower rate of return on investment may be appropriate for multiple-use reasons (Alexander and Edminster 1977b).

Control of Diameter Distribution

Control over distribution of tree diameters also is necessary to regulate yields under uneven-aged management. This most important step is accomplished by establishing the desired number of trees or basal area for each diameter class.

When used with flexibility, the quotient q between number of trees in successive diameter classes is a widely accepted means of calculating diameter distrubutions in uneven-aged stands (Meyer 1952). Values of q ranging between 1.3 and 2.0 (for 2-inch diameter classes) have been recommended for various situations. The lower the q, the smaller is the difference in number of trees between diameter classes. Stands maintained at a small q have a higher proportion of available growing stock in larger trees, for any residual stocking level, but may require periodic removal of the largest number of small trees in the diameter class where unregulated growing stock crosses the threshold into the portion of the stand to be regulated (Alexander and Edminster 1977b).

Consider, for example, differences in numbers of small and large trees maintained at a q level of 1.3, 1.5, 1.8 and 2.0 inches in stands with the same residual basal area (100 square feet) (table 1). At all stocking levels considered appropriate for future management goals, many small trees would have to be cut under lower q levels at the threshold diameter class (in this example the 4-inch class). Fewer larger trees would be retained under higher q levels.

In the absence of any experience, data, or good growth and yield information, the best estimate of numbers of trees to leave by diameter classes is to use the lowest q

Table 1.—Residual stand structures for 100 square feet of basal area and maximum tree diameter of 24 inches d.b.h. for various q values. All data are on a per-acre basis (Alexander and Edminster 1977b).

Diameter class (inches)	q = 1.3		q = 1.5		q = 1.8		q = 2.0	
	No. of trees	Basal area (ft.^{2})	No. of trees	Basal area (ft.^{2})	No. of trees	Basal area (ft.^{2})	No. of trees	Basal area (ft.^{2})
4	38.80	3.38	79.08	6.89	156.01	13.62	210.18	18.35
6	29.90	5.87	52.72	10.34	86.68	17.01	105.09	20.63
8	23.02	8.04	35.14	12.26	48.15	16.81	52.54	18.35
10	17.96	9.65	23.43	12.78	26.75	14.59	26.27	14.33
12	13.62	10.69	15.62	12.26	14.86	11.67	13.14	10.32
14	10.47	11.20	10.41	11.12	8.26	8.83	6.57	7.02
16	8.07	11.26	6.95	9.70	4.59	6.41	3.28	4.58
18	6.21	10.97	4.63	8.18	2.55	4.50	1.64	2.90
20	4.77	10.41	3.08	6.73	1.42	3.09	0.82	1.79
22	3.67	9.68	2.06	5.42	0.79	2.08	0.41	1.08
24	2.82	8.86	1.37	4.30	0.44	1.37	0.20	0.64
Total	159.14	100.01	234.49	99.98	350.50	99.98	420.14	99.99

value that is reasonable in terms of existing markets, stand conditions, and funds available for cultural work. Examination of plot data from a wide range of old-growth spruce-fir stands indicates that pretreatment distributions are likely to range between 1.3 and 1.8 for 2-inch classes. As a general recommendation, q levels between 1.3 and 1.5 appear to be reasonable initial goals for the first entry into unmanaged stands (Alexander and Edminster 1977b).

How to Determine Residual Stand Structure

Once goals for residual stocking, maximum tree diameter, and q levels have been selected, the specific structure for a stand can be calculated, provided that data are available to construct a stand table (Alexander and Edminster 1977b).

Two existing old-growth spruce-fir stands on the San Juan National Forest in Colorado are used to illustrate the procedure (stands A and B). The actual inventory data for stand A are shown in columns 1, 2, and 3 of table 2. A residual basal area of 80 square feet per acre in trees 3.0 inches in diameter and larger was chosen because: (1) it allows maximum reduction (30%) in present basal area consistent with previously developed recommendations for minimizing blowdown after partial cutting (Alexander 1973), and (2) it is the lowest basal area that appears to be a realistic timber management goal in spruce-fir stands. A maximum tree diameter of 24 inches d.b.h. was chosen, because it also appears to be a realistic goal to be attained in a reasonable period of time. Finally, a q of 1.5 was chosen, because it approximates the q in the natural stand, and does not require removal of many small trees. A lower q may be feasible; but it would require heavy cutting in lower diameter classes.

To determine the residual stand goal, the value of the residual density parameter k corresponding to a basal area of 80 square feet must be calculated. Values needed for this computation with a q of 1.5 are given in column 6 of table 3. The value of k is computed as

$$k = \frac{80.0}{0.57682 - 0.01454} = 142.2779$$

where 80.0 is the desired basal area per acre, 0.57682 is the table value for the desired maximum tree diameter class of 24 inches, and 0.01454 is the table value for the 2-inch class. Note that the value for the 2-inch class is subtracted from the 24-inch class value, because trees smaller than the 4-inch class are not considered in the management guidelines. Desired residual number of trees in each diameter class (column 4 of table 2) can be directly calculated by multiplying the proper diameter class values given in column 6 of table 4 by the value of k. The desired residual basal area in each diameter class (column 5 of table 2) can be calculated by multiplying the residual number of trees in each diameter class by the tree basal area given in table 5.

Comparing actual and desired diameter distributions shows where deficits and surpluses occur (fig. 31). To bring this stand under management, the number of trees should be allowed to increase in the diameter classes that are below the idealized stocking curve, with cutting limited to those diameter classes with surplus trees. As a guide, enough trees should be left above the curve in surplus diameter classes to balance the deficit in trees in diameter classes below the curve. In this example, all surplus trees will be cut in the 6- to 14-inch diameter classes, and in the 24- and 26-inch classes; no trees will be cut in the other classes. The final stand structure is shown in figure 32 and columns 6 and 7 of table 2. Columns 8 and 9 show the trees and basal area removed.

Table 2.—Actual stand conditions and management goals for stand A using basal area as the density measure. All data on a per acre basis—stand goals; q = 1.5, residual basal area = 80 square feet; maximum tree diameter of 24 inches d.b.h. (Alexander and Edminster 1977b).

	Actual stand		Residual stand goal		Final stand		Cut	
Diameter class (inches) (1)	No. of trees (2)	Basal area ($ft.^2$) (3)	No. of trees (4)	Basal area ($ft.^2$) (5)	No., of trees (6)	Basal area ($ft.^2$) (7)	No., of trees (8)	Basal area ($ft.^2$) (9)
4	57	4.97	63.23	5.52	57.0	4.98	0	0
6	53	10.41	42.16	8.28	42	8.24	11	2.16
8	46	16.06	28.10	9.81	28	9.77	18	6.28
10	32	17.45	18.74	10.22	19	10.36	13	7.09
12	16	12.57	12.49	9.81	12.5	9.81	3.5	2.75
14	14	14.97	8.33	8.90	8.5	9.09	5.5	5.88
16	6	8.38	5.55	7.75	6	8.38	0	0
18	3	5.30	3.70	6.54	3	5.30	0	0
20	5	10.91	2.47	5.39	5	10.91	0	0
22	0	0	1.64	4.33	0	0	0	0
24	2	6.28	1.10	3.46	1	3.14	1	3.14
26	2	7.37	—	—	—	—	2	7.37
Total	236	114.67	187.51	80.01	182	79.98	54	34.67

Table 3.—Values needed to compute k for different q ratios and diameter ranges using basal area as the density measure (Alexander and Edminster 1977b).

2-inch diameter classes	q ratio									
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
2	0.01983	0.01818	0.01678	0.01558	0.01454	0.01364	0.01283	0.01212	0.01148	0.01091
4	.09196	.07878	.06842	.06011	.05333	.04772	.04303	.03905	.03566	.03273
6	.23948	.19241	.15779	.13166	.11151	.09566	.08300	.07272	.06428	.05727
8	.47790	.36075	.28001	.22253	.18046	.14893	.12479	.10597	.09107	.07909
10	.81656	.57994	.42691	.32394	.25228	.20094	.16320	.13484	.11310	.09613
12	1.25990	.84297	.58963	.42825	.32124	.24775	.19574	.15793	.12979	.10840
14	1.80848	1.14132	.75999	.52966	.38380	.28758	.22179	.17539	.14175	.11675
16	2.45985	1.46605	.93116	.62428	.43828	.32009	.24181	.18806	.14997	.12221
18	3.20930	1.80854	1.09780	.70981	.48425	.34580	.25671	.19697	.15545	.12566
20	4.05043	2.16089	1.25606	.78523	.52209	.36565	.26753	.20308	.15901	.12779
22	4.97568	2.51618	1.40336	.85042	.55261	.38065	.27524	.20719	.16127	.12908
24	5.97669	2.86853	1.53820	.90583	.57682	.39181	.28063	.20991	.16269	.12985
26	7.04470	3.21314	1.65994	.95229	.59576	.40000	.28435	.21168	.16357	.13030
28	8.17072	3.54619	1.76854	.99077	.61041	.40593	.28689	.21282	.16410	.13056
30	9.34585	3.86479	1.86444	1.02232	.62162	.41019	.28861	.21354	.16443	.13071
32	10.56133	4.16688	1.94837	1.04797	.63012	.41322	.28975	.21400	.16462	.13079
34	11.80875	4.45107	2.02126	1.06864	.63652	.41536	.29052	.21429	.16474	.13084
36	13.08011	4.71658	2.08412	1.08520	.64131	.41685	.29102	.21447	.16480	.13087

Table 4.—Values needed to compute desired number of residual trees for different q ratios (Alexander and Edminster 1977b).

2-inch diameter classes	q ratio									
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
(1) D_i	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
2	0.909091	0.833333	0.769231	0.714286	0.666667	0.625000	0.588235	0.555556	0.526316	0.500000
4	.826446	.694444	.591716	.510204	.444444	.390625	.346021	.308642	.277008	.250000
6	.751315	.578704	.455166	.364431	.296296	.244141	.203542	.171468	.145794	.125000
8	.683013	.482253	.350128	.260308	.197531	.152588	.119730	.095260	.076734	.062500
10	.620921	.401878	.269329	.185934	.131687	.095367	.070430	.052922	.040386	.031250
12	.564474	.334898	.207176	.132810	.087791	.059605	.041429	.029401	.021256	.015625
14	.513158	.279082	.159366	.094865	.058528	.037253	.024370	.016334	.011187	.007813
16	.466507	.232568	.122589	.067760	.039018	.023283	.014335	.009074	.005888	.003906
18	.424098	.193807	.094300	.048400	.026012	.014552	.008433	.005041	.003099	.001953
20	.385543	.161506	.072538	.034572	.017342	.009095	.004960	.002801	.001631	.000977
22	.350494	.134588	.055799	.024694	.011561	.005684	.002918	.001556	.000858	.000488
24	.318631	.112157	.042922	.017639	.007707	.003553	.001716	.000864	.000452	.000244
26	.289664	.093464	.033017	.012599	.005138	.002220	.001010	.000480	.000238	.000122
28	.263331	.077887	.025398	.008999	.003425	.001388	.000594	.000267	.000125	.000061
30	.239392	.064905	.019537	.006428	.002284	.000867	.000349	.000148	.000066	.000031
32	.217629	.054088	.015028	.004591	.001522	.000542	.000206	.000082	.000035	.000015
34	.197845	.045073	.011560	.003280	.001015	.000339	.000121	.000046	.000018	.000008
36	.179859	.037561	.008892	.002343	.000677	.000212	.000071	.000025	.000010	.000004

Similar goals can be calculated using crown competition factor (CCF) as the density measure. Actual stand inventory data are shown in columns 1, 2, and 3 of table 6. Again, assuming a 30% reduction in stand density, the residual CCF should be 55.8. Data from column 6 of table 7 provides the following value of k:

$$k = \frac{55.8}{0.45417 - 0.04920} = 137.7880.$$

The value of k is then used to compute the residual number of trees and maximum crown area (MCA) values (columns 4 and 5 in table 6). Computations are similar to the previous method using basal area, except that a slightly different k value, and tree MCA values are used. The final stand structure and trees to be cut are shown in columns 6 through 9 in table 6.

It is not likely that unregulated stands will be brought under control with one cut or even a series of cuts. More likely, limitations imposed by stand conditions, windfall, and insect susceptibility will result in either over- or undercutting spruce-fir stands, at least at the first entry. Another example illustrates this, using information from

Table 5.—Values of tree basal area (in square feet) and maximum crown area (MCA) (in percent of an acre), by diameter (Alexander and Edminster 1977b).

2-inch diameter class	Basal area	MCA
2	0.022	0.074
4	.087	.129
6	.196	.199
8	.349	.284
10	.545	.385
12	.785	.501
14	1.069	.632
16	1.396	.778
18	1.767	.939
20	2.182	1.116
22	2.640	1.308
24	3.142	1.515
26	3.687	1.737
28	4.276	1.974
30	4.909	2.227
32	5.585	2.495
34	6.305	2.778
36	7.069	3.076

another stand on the San Juan National Forest (stand B). Actual stand inventory data are shown in columns 1, 2, and 3 in table 8. A residual basal area of 120 square feet per acre in trees 3.0 inches in diameter and larger would be a desirable stocking level, based on previous assumptions. This would be too heavy a cut, however, because it would open up the stand to possible damage from wind and subsequent loss to spruce beetles. With 223 square feet of basal area per acre in the stand, an initial reduction to 150 square feet per acre in trees 3.0 inches in diameter and larger would be appropriate. A q of 1.5 and a maximum tree diameter of 24 inches again were selected for the same reasons as in the first example. Procedures used to obtain columns 4 and 5 in table 8 are also the same as before (table 2).

A comparison of curves of actual desired diameter distributions shows where deficits and surpluses occur (fig. 33). In this example, the bulk of trees removed come from the 14- to 20-inch diameter classes; but no more than 50% of the trees would be removed in the largest diameter classes. Few or no trees would be cut in the smaller diameter classes. The final stand structure is shown in figure 34 and columns 6 and 7 in table 8.

How to Handle Small Trees

The threshold diameter class also must be determined. Calculations often are made down to the 4-inch diameter class by 2-inch classes, because there are usually many small trees in spruce-fir stands that are below minimum merchantable diameter. They compete with larger stems for growing space. More important, these trees provide ingrowth into merchantable size classes needed to practice individual-tree selection silviculture.

Although small trees should not be ignored in inventory and record keeping, it may be neither desirable nor possible to regulate the number of them. In spruce-fir forests in the central Rocky Mountains, minimum merchantable diameter is usually 7 to 8 inches. Regulation of the number of trees below this size requires an investment in silvicultural work that may not be recaptured under current market conditions. However, if trees below minimum merchantable size are left unregulated, cutting must always be heavy in the threshold diameter

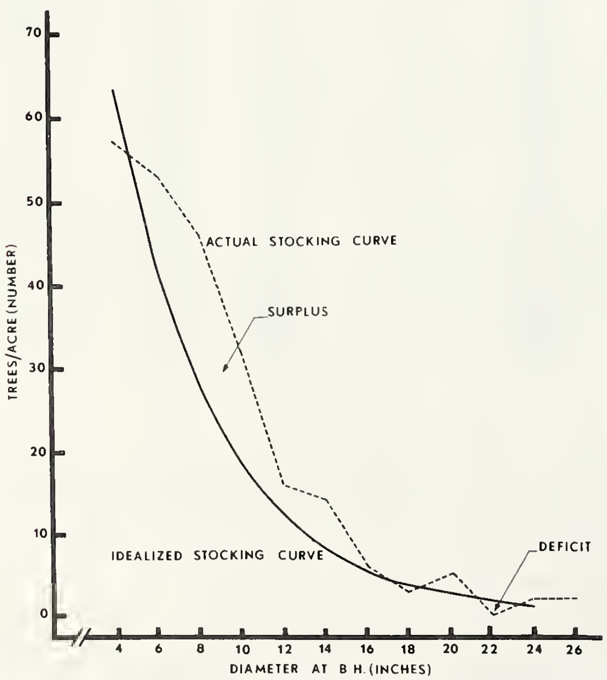

Figure 31.—Actual stocking curve of stand A from inventory data and the idealized stocking curve based on stand structure goals.

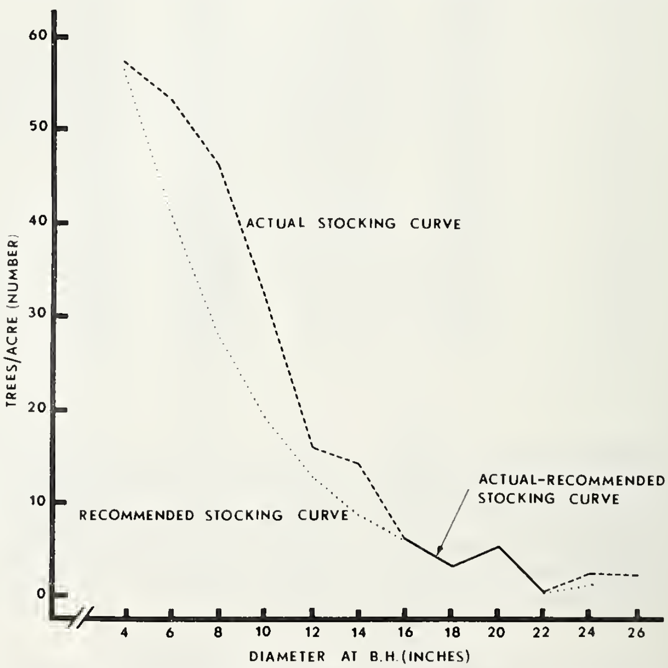

Figure 32.—Actual stocking curve of stand A and recommended stocking curve based on stand structure goals, actual stand structure, and management and silvicultural constraints.

Table 6.—Actual stand conditions and management goals for stand A using crown competition factor (CCF) as the density measure. All data are on a per acre basis (Alexander and Edminster 1977b).

Diameter class (inches) (1)	Actual stand: No. of trees (2)	Actual stand: Total MCA (3)	Residual stand goal: No. of trees (4)	Residual stand goal: Total MCA (5)	Final stand: No. of trees (6)	Final stand: Total MCA (7)	Cut: No. of trees (8)	Cut: Total MCA (9)
		CCF		CCF		CCF		CCF
4	57	7.35	61.24	7.90	57	7.35	0	0
6	53	10.55	40.83	8.13	41	8.16	12	2.39
8	46	13.06	27.22	7.73	27	7.67	19	5.39
10	32	12.32	18.14	6.98	18	6.93	14	5.39
12	16	8.02	12.10	6.06	12	6.01	4	2.01
14	14	8.85	8.06	5.09	8	5.09	6	3.76
16	6	4.67	5.38	4.19	6	4.67	0	0
18	3	2.82	3.58	3.36	3	2.82	0	0
20	5	5.58	2.39	2.67	5	5.58	0	0
22	0	0	1.59	2.08	0	0	0	0
24	2	3.30	1.06	1.61	1	1.52	1	1.51
26	2	3.47	—	—	—	—	2	3.47
Total	236	79.72	181.59	55.80	178	55.80	54	23.92

Table 7.—Values needed to compute k for different q ratios and diameter ranges using crown competition factor (CCF) as the density measure (Alexander and Edminster 1977b).

2-inch diameter classes (1)	q ratio 1.1 (2)	1.2 (3)	1.3 (4)	1.4 (5)	1.5 (6)	1.6 (7)	1.7 (8)	1.8 (9)	1.9 (10)	2.0 (11)
2	0.06709	0.06150	0.05677	0.05271	0.04920	0.04612	0.04341	0.04100	0.03884	0.03690
4	.17354	.15094	.13298	.11843	.10644	.09644	.08798	.08075	.07452	.06910
6	.32305	.26611	.22356	.19095	.16541	.14502	.12848	.11488	.10353	.09397
8	.51730	.40326	.32314	.26498	.22159	.18842	.16254	.14197	.12536	.11175
10	.75635	.55798	.42683	.33657	.27228	.22513	.18965	.16234	.14091	.12378
12	1.03904	.72570	.53058	.40308	.31625	.25498	.21040	.17707	.15155	.13161
14	1.36325	.90202	.63127	.46301	.35323	.27852	.22580	.18739	.15862	.13654
16	1.72620	1.08296	.72664	.51573	.38358	.29663	.23695	.19445	.16320	.13958
18	2.12459	1.26502	.81523	.56120	.40802	.31030	.24487	.19918	.16611	.14142
20	2.55486	1.44526	.89618	.59978	.42737	.32045	.25041	.20231	.16793	.14251
22	3.01324	1.62128	.96916	.63208	.44249	.32789	.25422	.20434	.16905	.14314
24	3.49590	1.79117	1.03417	.65879	.45417	.33327	.25682	.20565	.16974	.14351
26	3.99905	1.95352	1.09152	.68068	.46309	.33713	.25858	.20649	.17015	.14373
28	4.51897	2.10730	1.14167	.69845	.46986	.33987	.25975	.20701	.17040	.14385
30	5.05209	2.25184	1.18518	.71276	.47494	.34180	.26053	.20734	.17054	.14391
32	5.59503	2.38678	1.22267	.72422	.47874	.34315	.26104	.20755	.17063	.14395
34	6.14461	2.51199	1.25478	.73333	.48156	.34409	.26137	.20768	.17068	.14397
36	6.69785	2.62752	1.28213	.74053	.48364	.34474	.26159	.20775	.17071	.14399

classes to bring ingrowth trees down to the desired number. It also means that more growing space is required for small trees than called for by the idealized stand structure. Moreover, the higher the threshold diameter class, the greater is the proportion of the stand that is unregulated. More growing space is occupied by trees of low value that will be cut as soon as they cross the threshold diameter (Alexander and Edminster 1977b).

Marking Trees

After residual stocking goals have been calculated and a decision has been made on how to handle small trees, the stand must be marked. Marking is difficult in spruce-fir stands, because the marker must designate cut or leave trees, usually with one pass through the stand, based on limited inventory data. At the same time, the marker must apply good silviculture and be aware of

Table 8.—Actual stand conditions and management goals for stand B using basal area as the density measure[1]. All data on a per acre basis—stand goals; q = 1.5, residual basal area = 150 square feet, maximum tree diameter of 24 inches d.b.h. (Alexander and Edminster 1977b).

Diameter class (inches)	Actual stand		Residual stand goal		Final stand		Cut	
	No. of trees	Basal area (ft.[2])	No. of trees	Basal area (ft.[2])	No., of trees	Basal area (ft.[2])	No., of trees	Basal area (ft.[2])
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
4	109	9.52	118.56	10.35	109	9.52	0	0
6	49	9.62	79.04	15.52	49	9.62	0	0
8	54	18.85	52.70	18.40	54	18.85	0	0
10	31	16.91	35.13	19.16	31	16.91	0	0
12	24	18.85	23.42	18.39	23	18.06	1	0.79
14	29	31.00	15.61	16.69	17	18.17	12	12.83
16	26	36.30	10.41	14.54	13	18.15	13	18.15
18	13	22.97	6.94	12.26	8	14.14	5	8.83
20	10	21.82	4.63	10.10	5	10.91	5	10.91
22	10	26.40	3.08	8.13	5	13.20	5	13.20
24	1	3.14	2.06	6.47	1	3.14	0	0
26	2	7.37	—	—	—	—	2	7.37
Total	358	222.75	351.58	150.01	315	150.67	43	72.18

[1]*Residual density parameter k for this example is computed as*

$$k = \frac{150.0}{0.57682 - 0.01454} = 266.77$$

[2]*Numbers of residual trees in each diameter class (col. 4) are computed by multiplying values in col. 6, table 4 by k.*

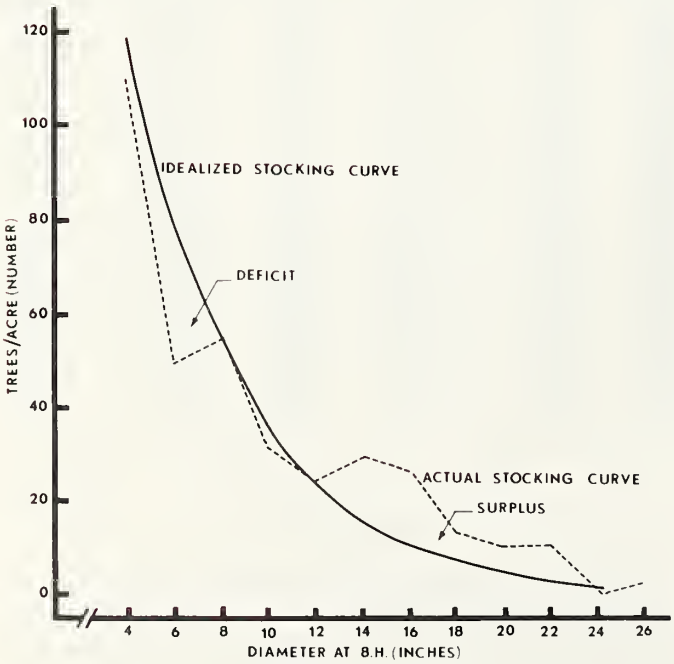

Figure 33.—Actual stocking curve of stand B from inventory data and the idealized stocking curve based on stand structure goals.

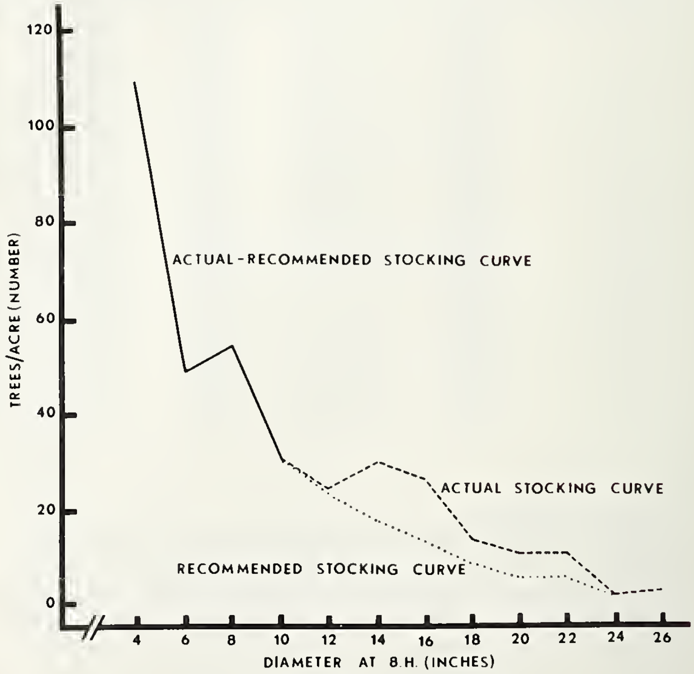

Figure 34.—Actual stocking curve of stand B and recommended stocking curve based on stand structure goals, actual stand structure, and management and silvicultural constraints.

economic limitations. As a general rule, good silvicultural prescriptions are more important than strict adherence to structural goals, especially in unregulated stands being cut for the first time. However, marking without a structural goal—or prescribing structural goals that cannot be attained or applied—defeats the objective of regulation.

Because marking for individual tree selection is more complex than for other systems, some formal control procedure is necessary. Often, only an estimate of the initial and desired residual diameter distribution is needed. With these estimates, basal areas and number of trees to be removed per acre by diameter classes can be determined. Control is maintained by a process of successive checks of residual compared to the goal. For example, the markers should systematically make prism estimates of the residual stand after marking, recording trees by 2- or 4-inch classes on a standard cumulative tally sheet. Periodically, they should convert the prism tally to trees per acre, and compare their average prism estimate to the structural goal. Markers must then adjust to any serious deviation from the structural goal, such as too heavy marking in some diameter classes and too light in others. Their next check will determine if progress is being made or if further changes are needed. By this process, the average residual stand should come fairly close to the structural goal (Alexander and Edminster 1977b).

Recommendations for Selection Cutting

These are based on experience, windfall risk, and spruce beetle susceptibility. Selection cutting methods are appropriate for three- and multi-storied stands with irregular or uneven-aged stand structure. Individual tree selection should be confined to stands with uniform spacing. Group selection can be used in stands with either clumpy-groupy spacing or uniform spacing. Selection cutting methods are not appropriate in high wind risk situations, or in stands sustaining a spruce beetle attack, or in stands where enough beetles are present within the stand or adjacent stands to make successful attacks.

Stand Structure Goals, Cutting Treatments, and Reentry Schedules

In low wind risk situations, not more than 30% to 40% of the stand basal area should be removed. With individual tree selection, the cut should be distributed over the entire area. With group selection, not more than one-third of area should be cut. If the stand is clumpy, the size of opening should be determined by the size of the clump. If the stand is uniformly spaced, the size of opening should not exceed two times tree height.

In above average wind risk situations, not more than 20% to 20% of the stand basal area should be removed. Distribute the cut over the entire area with individual tree selection. Not more than one-fourth of the area should be cut with group selection. Keep the openings small. If the stand is clumpy, the opening should be no larger than the size of the clump. If the stand is uniformly spaced, openings should not exceed 1 times tree height.

Maximum diameter should not exceed that attained in the unmanaged stand. The diameter distribution should be set at a q value that most closely approximates the natural q value of the stand. However, remember that low q values require cutting a larger number of trees at the threshold diameter class and high q values retain few larger trees. The threshold value should be set at the smallest diameter class practical. All trees below the threshold diameter class are unregulated. Some diameter classes will have a surplus of trees and some will have a deficit. Surpluses and deficits must be balanced if the residual basal area is to maintained. Subsequent entries should be made at 10- to 30-year intervals. While it would be desirable to enter the stand at 10-year intervals, it is not likely that this will be possible in most instances. Some diameter classes will not be completely represented; therefore, volumes available for cutting may not warrant a 10-year reentry until a controlled diameter distribution is attained.

Protecting the Residual Stand

Protection of the residual stand is critical with individual-tree selection cutting because of frequent entries into the stand once a controlled diameter distribution is attained. Damage can result from felling, skidding, and slash disposal.

Felling damage can be reduced by using group selection and dropping trees in the openings, or marking a small clump of trees where felling one large tree will damage several adjacent trees. Procedures outlined for protecting the residual for simulated shelterwood and disposing of slash for shelterwood cutting should be followed here.

COSTS OF SALE ADMINISTRATION AND LOGGING

Costs are important in harvesting spruce-fir stands, because the value of the timber has been moderate to low, and logging can be difficult because of terrain. One of the most important factors affecting the administrative cost of selling timber is the number of entries needed for harvesting. Clearcutting and simulated shelterwood require only one entry. Standard shelterwood requires two to three entries. Group shelterwood, and individual tree and group selection require from three to six entries, depending upon cutting cycles. In managed stands, even-aged systems could have additional entries for thinnings; but the number of entries under uneven-aged systems would not change (Alexander 1977).

Costs of sale layout, marking, and sale contract administration are lower for clearcutting, simulated and group shelterwood, group selection (when groups are near the maximum size), and the final cut of standard shelterwood than for individual tree selection, and the intermediate, preparatory and seed cuts of standard

shelterwood. Costs are reduced, because only cutting boundaries are marked, and no time is spent marking each tree to cut or leave. Sale administration is easier, because there are no residual trees to protect and no opportunity to cut unmarked trees. However, reproduction must be protected at the time of final cut under any shelterwood system (Alexander 1977). Costs for selection methods are further increased, because highly skilled individuals are required to recognize, mark, and protect the trees needed to be left uncut in order to obtain and/or maintain the diameter distribution.

Timber harvesting usually requires road construction, because large acreages of spruce-fir forests are in unmanaged old-growth stands. Clearcutting is the most economical method in terms of volume removed per unit of road, while individual tree selection is the most expensive. Development of a transportation system to manage spruce-fir forests is a costly front-end investment that will require funding in addition to the value of stumpage at the time of first entry. Once the transportation system has been constructed, roads costs should be independent of cutting method (Alexander 1977).

In addition to producing maximum volume per acre in one operation, clearcutting permits the greatest flexibility in selection of logging equipment and minimum concern for protection of residual trees. The first entry of a standard shelterwood is intermediate in volume production per acre, requires moderate concern for the residual stand, and places some constraints on selection of equipment. The final cut of a standard shelterwood or simulated shelterwood has the advantages of clearcutting, except for the need to protect the new stand. Individual tree selection requires maximum concern for the residual stand. Group selection and group shelterwood require slightly less if the size of opening is near maximum. Under uneven-aged and group shelterwood cutting methods, volumes per entry are intermediate, size-class diversity of products harvested is maximum, and selection of logging equipment is restricted to smaller or specialized machines.

MULTIPLE-USE SILVICULTURE

SOIL AND WATER RESOURCES

Water Yield

In spruce-fir forests, where approximately 90% of natural streamflow (12 to 15 inches) comes from melting snow, water production is increased by cutting openings in the canopy (fig. 35). Size and arrangement of openings are critical. Largest increases in water available for streamflow (2.0+ inches) result when 30% to 40% of a drainage is harvested in small clearcut patches (3 to 5 acres) dispersed over the entire watershed (Leaf 1975; Leaf and Alexander 1975; Troendle 1982, 1983a, 1983b; Troendle and Leaf 1981). With this pattern, wind movement across the canopy is changed so that more snow accumulates in the openings than under adjacent stands.

Figure 35.—Three-acre openings cut to increase streamflow, Fraser Experimental Forest.

Total snowfall in the drainage may or may not be increased by cutting, depending upon aspect (Hoover and Leaf 1967, Troendle and Meiman 1984); but melt occurs earlier and at an increased rate in the openings, causing the rising limb of the hydrograph to occur earlier than before timber harvest. Most of the increase in flow occurs before the peak, which may be somewhat higher; but recession flows are about the same as before harvest. Increase in streamflow is not likely to significantly diminish for 20 to 30 years, and treatment effect will not disappear until the new stand in the openings is tall enough to change the snow accumulation pattern.

At that time, a number of alternatives can be considered. (1) Recut the original openings. The remaining area would be retained as continuous high forest; trees would be harvested periodically on an individual-tree basis. Ultimately, the reserve stand would approach an all-aged structure with the overstory canopy remaining at about the same height, although the original overstory could not be maintained indefinitely. (2) Make a light cut distributed over the entire watershed, removing about 20% to 30% of the basal area on an individual-tree basis or in small groups. The objective would be to open up the stand enough to develop windfirmness, and salvage low-vigor and poor-risk trees. Openings five to eight times tree height can then be cut on about one-third of the area. The remaining two-thirds of the area would be retained as permanent high forest, with trees periodically removed on an individual-tree basis or in small groups. (3) Another alternative that would integrate water and timber production would be to harvest all of the old-growth in a cutting block in a series of cuts spread over 120 to 160 years. Each cutting block would contain at least 300 acres, subdivided into circular or irregular-shaped units approximately 2 acres in size or four to five times (in diameter) the height of the general canopy level. At periodic intervals, some of these units, distributed over the cutting block, would be harvested and the openings would be regenerated. The interval between cuttings could vary from as often as every 10 years to as infrequently as every 30 to 40 years. The percentage of units cut at each interval would be determined by cutting cycle/rotation age × 100. At the end of one rotation, each

cutting block would be composed of groups of trees in several age classes ranging from reproduction to trees ready for harvest. The tallest trees would be somewhat shorter than the original overstory; but any adverse effect on snow deposition should be minimized by keeping the openings small and widely spaced (Alexander 1974).

Cutting openings larger than 5 acres may be less efficient in increasing streamflow, because as opening size increases, wind can scour deposited snow causing it to evaporate into the air or blow into adjacent stands where recharge requirements and evapotranspiration are greater. However, these larger openings can be managed to minimize wind scour and maintain snowpack on the site. By leaving residual stems standing and moderately heavy slash in place to provide roughness to hold snow, 20% to 30% more water can be retained in the snowpack than in the uncut forest, even in relatively large openings.

Group selection and group shelterwood cutting can be nearly as favorable for water production as patch clearcutting, if openings are near the maximum size of 2 acres. Increase in water available for streamflow under individual tree selection will be less than cutting small openings but still significantly higher than in the uncut forest. Canopy reduction by removing trees on an individual basis results in less interception of snow and subsequent evaporation from the canopy. This combined with any other reduction in consumptive use (ET) can result in greater streamflow (Troendle and Meiman 1984).

Standard shelterwood results in increases similar to individual tree selection as long as an overstory remains. After final harvest under any standard shelterwood alternative, water available for streamflow may be expected to increase to the level obtained under patch clearcutting, provided that the area cut is similar in size and arrangement to openings recommended for patch clearcutting. The interval of increased water yield will be proportional to time required for the replacement stand to grow tall enough to modify wind movement across the canopy (Alexander 1977).

Soil Erosion and Water Quality

Soil and site conditions are not the same in all spruce-fir forests; but the careful location, construction, and maintenance of skid and haul roads associated with any silvicultural system should not cause a lasting increase in sedimentation. For example, on the Fool Creek drainage in central Colorado, where about 12 miles of main and secondary roads were constructed to remove timber in alternate clearcut strips from about one-third of the drainage, annual sediment yields during road construction and logging were only about 200 pounds per acre (Leaf 1970), and decreased rapidly after logging, despite a persistent increase in runoff. Annual sediment yields after logging have averaged about 43 pounds per acre, compared to 11 to 31 pounds from undisturbed watersheds (Leaf 1975).

Nutrient Losses and Stream Water Temperature Changes

Removal of logs in timber harvest represents a small and temporary net loss of nutrients, because only a minor proportion of the nutrients taken up by a tree is stored in the bole. Clearcutting spruce-fir forests results in a greater immediate loss than individual tree selection; but over a rotation, the losses would balance out because of more frequent cuts under the selection system. Furthermore, nutrients lost after clear cutting should be replaced in 10 to 20 years through natural cycling as regeneration becomes established (Alexander 1977).

Comparison of streamflow from logged and unlogged subalpine watersheds in central Colorado provided some indication of effect on chemical water quality. Ten years after clearcutting, cation concentration during a 10-week period was 1.8 ppm greater and cation outflow 5.2 pounds per acre per year greater on the logged watershed (Stottlemyer and Ralston 1968).

Increases in stream temperature can be avoided, even with clearcutting, by retaining a border of trees along stream channels. Actually, clearcutting to the stream channel and subsequent warming of the water may be advantageous in spruce-fir forests, where streams are frequently small and too cold to support adequate food supplies for fish (Alexander 1977).

WILDLIFE AND RANGE RESOURCES

Game Habitat

Spruce-fir forests provide summer habitat for mule deer and elk, and yearlong habitat for blue grouse (*Dendragapus obscurus* Say). Clearcutting, group shelterwood, and group selection provide the largest increases in quantity and quality of forage for big game; but use often is limited by the amount of cover available for hiding, resting, and ruminating. Furthermore, game populations are not directly related to forage availability on summer ranges, because carrying capacity of winter ranges limits the number of animals. Mature unlogged spruce-fir stands in Colorado produce enough forage to support more mule deer than are presently estimated to occupy summer ranges (Regelin et al. 1974).

Dispersed openings 2 to 20 acres in size are used more by deer and elk than smaller or larger openings or uncut timber (Regelin and Wallmo 1978, Reynolds 1966, Wallmo 1969, Wallmo et al. 1972). Small openings provide little diversity, and overly large openings radically alter habitat, especially if they are coupled with extensive site preparation and tree planting. As trees grow to seedling and sapling size, forage production in cleared areas diminishes, but cover increases. Forage increases again as stands reach sawlog size and cover approaches the maximum for the spruce-fir type.

Openings created by harvesting are preferred to natural openings, because the vegetation that initially comes in on cutover areas is more palatable to deer and elk. Reynolds (1966) suggested that openings be main-

tained by cleaning up the logging slash and debris, removing new tree reproduction, and seeding the area to forage species palatable to big-game. However, because natural succession on areas is likely to replace the more palatable species in 15 to 20 years (Regelin and Wallmo 1978), a more desirable alternative would be to cut new openings periodically while allowing the older cuttings to regenerate. That would provide a constant source of palatable forage and the edge effect desired. The openings created should be widely spaced, with stands between openings maintained as high forest (Alexander 1977).

One alternative that would integrate wildlife habitat improvement with timber production would be to cut about one-sixth of a cutting block every 20 years in openings about four to five times tree height. Each working circle would be subdivided into a number of cutting blocks (of at least 300 acres), so that not all periodic cuts would be made in a single year on a working circle. Such periodic cutting would provide a good combination of numbers and species of palatable forage plants and the edge effect desired, while creating a several-aged forest of even-aged groups (Alexander 1974).

Standard shelterwood cutting provides less forage for big game than cutting methods that create openings; and the reduction is in proportion to the density of the overstory and length of time it is retained. Shelterwood cutting also provides less cover than an uncut forest. Individual tree selection provides forage and cover comparable to uncut forests, thus maintaining one type of habitat at the expense of creating diversity (Alexander 1977).

Game animals other than deer or elk also are influenced by the way forests are managed. For example, with the decrease in wildfires, some reduction in stand density by logging may be necessary to create or maintain drumming grounds for male blue grouse. Standard shelterwood, group shelterwood, or group selection cutting that opens up the stand enough to allow regeneration to establish in thickets provides desirable cover. Small, dispersed clearcuts (5 to 10 acres) also are favorable if thickets of new reproduction become established (Martinka 1972).

Nongame Habitat

Little information is available on the relationship of cutting methods in spruce-fir forests to specific nongame habitat requirements; but it is possible to estimate probable effects. Clearcutting, group shelterwood, and group selection that create small, dispersed openings provide a wide range of habitats attractive to some birds and small mammals by increasing the amount of nontree vegetation—at least initially—and length of edge between dissimilar vegetation types. On the Fool Creek watershed, for example, where 40% of the timber was cleared in alternate strips one to six chains wide, many species of birds feed in openings and nest in trees along the edge. In contrast, only woodpeckers and sapsuckers have been observed in adjacent uncut stands (Myers and Morris 1975). However, Scott et al. (1982) compared numbers and species of nongame birds on two 100-acre subdrainages on Deadhorse Creek, in the Fraser Experimental Forest. One-third of one subdrainage was clearcut in 3-acre patches; the other was left uncut. They found that total numbers of birds did not significantly change with cutting. However, there was a small postharvest decline in the "foliage nesting" and "picker" and "gleaner" feeding guilds. There were no significant changes in small mammal populations after timber harvest.

In the central Rocky Mountains, spruce-fir forests commonly occur on habitat types that can support lodgepole pine and aspen. Where these species are components of existing spruce-fir stands, clearcutting can increase their representation in the replacement stand, thereby creating a diversity in cover types. This increase in diversity is generally desirable for a variety of nongame wildlife.

Standard shelterwood cutting provides a variety of habitats attractive to species that forage in stands with widely spaced trees, but not to those that require closed forests or fully open plant communities. Under this method, trees are still available for nesting, denning, and feeding until the final harvest, when consideration should be given to retaining some of the snags and live trees with cavities (Alexander 1977). To insure future cavities, Scott et al. (1978) recommended leaving all broken-top snags greater than 8 inches d.b.h. and live trees with broken-tops or scars.

Harvesting old-growth timber can be devasting to species that nest or den in snags and in cavities of live trees, feed largely on tree seeds, or require solitary habitats with continuous forest cover. Individual tree selection provides the least horizontal diversity, and favors species attracted to uncut forests or that require vertical diversity. However, snags and live tree cavities can be retained under any silvicultural system (Alexander 1977).

Livestock Grazing

Much grazing land is adjacent to or intermingled with spruce-fir forests. While the quantity and quality of forage produced varies with habitat type, forage production under a mature canopy is usually light and generally not readily accessible to livestock. The quantity and quality of forage increases in proportion to the amount of canopy removed. Utilization of available forage usually is greater in large clearcut areas, because forage is more accessible to livestock. Forage production in openings decreases rapidly as new trees grow out of the seedling-sapling stage; and it can be maintained only by frequent cuttings (Alexander 1977).

RECREATION AND ESTHETICS

Spruce-fir forests provide a variety of recreation opportunities. Users who hike, backpack, ski, tour, or view scenery are generally attracted to forests whose natural appearance is little altered by human activities (Calvin

1972). In contrast, hunters have best success where human activities are apparent—timber sales and other areas readily accessible by roads. Fishing is mostly done in accessible lakes, reservoirs, and streams. Generally, most camping opportunities are at both publicly and privately developed sites served by roads. Most scenery viewing is by automobile on developed roads. Moreover, most of the winter use of snowmobiles for recreation in spruce-fir forests is on roads. Finally, some forms of recreation, such as downhill skiing and mountain home development, require drastic modification of the natural forest landscape (Alexander 1977).

Clearcutting has the greatest visual impact, and individual tree selection has the least. However, variety typical of forests at the highest elevations—whose texture is broken by natural openings—is preferred to the monotony of vast, unbroken forest landscapes at middle and lower elevations (Kaplan 1973). In addition, aspen, a seral species, which is a major esthetic resource, can be maintained by clearcutting.

To enhance amenity values, openings cut for timber and water production and wildlife habitat improvement should be a repetition of natural shapes, visually tied together to create a balanced and unified pattern that will complement the landscape (Barnes 1971). This is especially important for openings in the middleground and background seen from a distance. Standard or simulated shelterwood, or individual tree selection can be used to retain a landscape in foregrounds. Well planned clearcut openings also can be used to create and maintain vistas along major road systems.

Individual tree selection, group selection, and group shelterwood cutting are appropriate in high-use recreation areas, travel influence zones, scenic-view areas, and lands adjacent to ski runs—and also near support facilities and subdivision developments where permanent forest cover is desired. The visual impact of logging can be minimized by cleanup of debris and slash and by careful location of roads (Alexander 1977).

COMPARISON OF CUTTING METHODS

A comparison of the effects of different silvicultural systems, and cutting methods, and their modifications, on resource values and timber economics in spruce-fir forests is shown in figure 36. These relative rankings are based on research and experience, and are subject to change as additional information on resource interactions becomes available.

No silvicultural system or cutting method (including no cutting at all) meets all resource needs. Cutting small openings provides maximum yields of timber at minimum costs, promotes the largest increases in water production without serious reduction in quality, produces diversity in food supply and cover favored by many wildlife species, and is necessary for the development of recreation sites for skiing and home subdivisions. Production and utilization of livestock forage are less than on larger openings, while clearcutting in any form destroys the habitat of wildlife species that dwell in closed

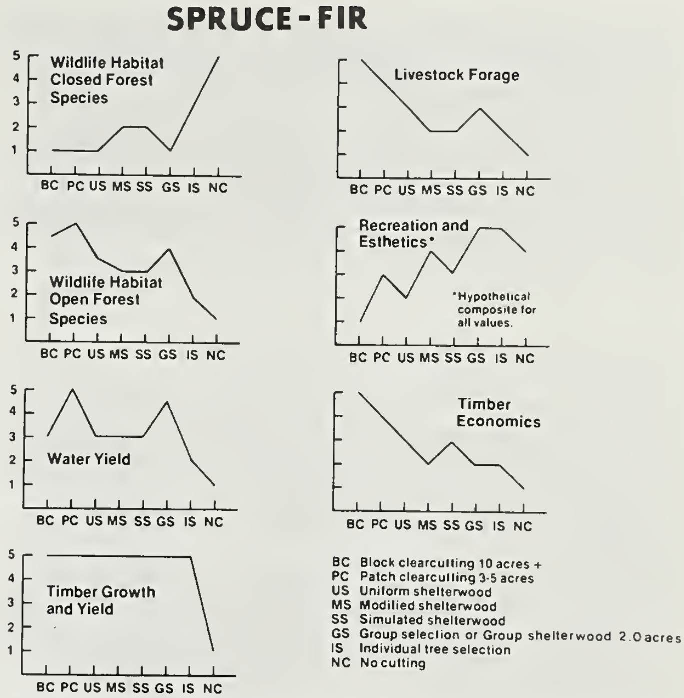

Figure 36.—Relative ranking of the effects of cutting methods on the resources of spruce-fir forests. Scale: 1 = least favorable, 5 = most favorable.

forests. Clearcutting can create adverse visual effects if no thought is given to the size and arrangement of the openings; but it can also be used to create landscape variety that will enhance amenity values.

Standard and simulated shelterwood cutting also provide maximum timber yields over the same time interval, but at increased costs; they produce a wide range of wildlife habitats, but with less forage than openings and less cover than uncut forests. Water yields are increased significantly over natural streamflow, but not as much as clearcutting small openings. Shelterwood cutting provides a partial retention of the forest landscape, particularly when the overstory is retained for a long time (Alexander 1977).

Group selection and group shelterwood cutting, with the size of opening near the maximum, favor and discriminate against the same resource values as patch or strip clearcutting. They are more expensive and less flexible, however. Individual tree selection cutting can maintain high levels of timber production; but it is the most expensive harvesting method. Water yields are greater than in uncut forests. Individual tree selection cutting provides minimum horizontal diversity in wildlife habitat, but favors species attracted to uncut forests. It also provides good partial retention of the natural forest landscape. Group selection with very small openings accomplishes about the same things as individual tree selection (Alexander 1977).

Not all resource needs can be met on a given site, nor is any one cutting method compatible with all uses. Land managers must recognize the potential multiple-use values of each area, determine the primary and secondary uses, and then select the management alternative that is most likely to enhance or protect these values. On an

individual site, some uses probably must be sacrificed or diminished to maintain the quantity and quality of others (Alexander 1977).

Within a given area, a variety of cutting methods usually should be prescribed to meet diverse management objectives. However, cutting methods should take advantage of existing stand conditions and access, and account for damaging agents, as well as management objectives.

LITERATURE CITED

Alexander, Robert R. 1956. A comparison of growth and mortality following cutting in old-growth mountain spruce-fir stands. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Research Note 20, 4 p. Fort Collins, Colo.

Alexander, Robert R. 1957. Damage to advanced reproduction in clearcutting spruce-fir. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Research Note 27, 3 p. Fort Collins, Colo.

Alexander, Robert R. 1963. Harvest cutting old-growth mountain spruce-fir in Colorado. Journal of Forestry 61:115-119.

Alexander, Robert R. 1964. Minimizing windfall around clear cuttings in spruce-fir forests. Forest Science 10:130-142.

Alexander, Robert R. 1966. Stocking of reproduction on spruce-fir clearcuttings in Colorado. USDA Forest Service Research Note RM-72, 8 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1967. Windfall after clearcutting on Fool Creek—Fraser Experimental Forest, Colorado. USDA Forest Service Research Note RM-92, 11 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1968. Natural reproduction of spruce-fir after clearcutting in strips, Fraser Experimental Forest. USDA Forest Service Research Note RM-101, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1969. Seedfall and establishment of Engelmann spruce in clearcut openings: A case history. USDA Forest Service Research Paper RM-53, 8 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1973. Partial cutting in old-growth spruce-fir. USDA Forest Service Research Paper RM-110, 16 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1974. Silviculture of subalpine forests in the central and southern Rocky Mountains: The status of our knowledge. USDA Forest Service Research Paper RM-121, 88 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1977. Cutting methods in relation to resource use in central Rocky Mountain spruce-fir forests. Journal of Forestry 75:395-400.

Alexander, Robert R. 1980. Engelmann spruce-subalpine fir 206. p. 86-87. *In* F. A. Eyre, editor. Forest cover types of the United States and Canada. Society of American Foresters, Washington, D.C.

Alexander, Robert R. 1983. Seed: seedling ratios of Engelmann spruce after clearcutting in the central Rocky Mountains. USDA Forest Service Research Note RM-426, 6 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1984. Natural regeneration of Engelmann spruce after clearcutting in the central Rocky Mountains in relation to environmental factors. USDA Forest Service Research Paper RM-254, 17 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1985a. Diameter and basal area distributions in old-growth spruce-fir stands on the Fraser Experimental Forest. USDA Forest Service Research Note RM-451, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R. 1985b. Major habitat types, community types, and plant communities in the Rocky Mountains. USDA Forest Service General Technical Report RM-123, 105 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., and Carleton B. Edminster. 1977a. Regulation and control of cut under uneven-aged management. USDA Forest Service Research Paper RM-182, 7 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., and Carleton B. Edminster. 1977b. Uneven-aged management of old-growth spruce-fir forests: Cutting methods and stand structure goals for initial entry. USDA Forest Service Research Paper RM-186, 12 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., and Carleton B. Edminster. 1980. Management of spruce-fir in even-aged stands in the central Rocky Mountains. USDA Forest Service Research Paper RM-217, 14 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., and Carleton B. Edminster. 1983. Engelmann spruce seed dispersal in the central Rocky Mountains. USDA Forest Service Research Note RM-424, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., and Orville Engelby. 1983. Engelmann spruce—subalpine fir. p. 59-64. *In* R. E. Burns, technical compiler. Silvicultural systems for major forest types of the United States. U.S. Department of Agriculture, Forest Service, Agricultural Handbook 445, 191 p. Washington, D.C.

Alexander, Robert R., Raymond C. Shearer, and Wayne D. Shepperd. 1984. Silvical characteristics of subalpine fir. USDA Forest Service General Techical Report RM-115, 29 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., and Wayne D. Shepperd. 1984. Silvical characteristics of Engelmann spruce. USDA Forest Service General Technical Report RM-114, 38 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Alexander, Robert R., Ross K. Watkins, and Carleton B. Edminster. 1982. Engelmann spruce seed production on the Fraser Experimental Forest, Colorado. USDA Forest Service Research Note RM-419, 6 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Baker, Frederick S. 1949. A revised tolerance table. Journal of Forestry 47:179-181.

Barnes, R. Lawrence. 1971. Patterned tree harvest proposed. Western Conservation Journal 28:44-47.

Bond, E. W. 1952. Growing stock differences in even-aged and all-aged forests. Journal of Forestry 50:691-693.

Bourne, R. 1951. A fallacy in the theory of growing stock. Forestry 24:6-18.

Buffam, P. E., C. K. Lister, R. E. Stevens, and R. H. Frye. 1973. Fall cacodylic acid treatments to produce lethal traps for spruce beetles. Environmental Entomology 2:259-262.

Calvin, J. S. 1972. An attempt at assessing preferences for natural landscapes. Environment and Behavior 4(4):447-470.

Furniss, R. L., and V. M. Carolin. 1977. Western forest insects. U.S. Department of Agriculture, Forest Service, Miscellaneous Publication No. 1339, 654 p. Washington, D.C.

Green, Allen W., and Duane D. Van Hooser. 1983. Forest resources of the Rocky Mountain states. USDA Forest Service Research Bulletin INT-33, 127 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Hanley, David P., Wyman C. Schmidt, and George M. Blake. 1975. Stand succession and successional status of two spruce-fir forests in southern Utah. USDA Forest Service Research Paper INT-176, 16 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Hawksworth Frank G., and Delbert Wiens. 1972. Biology and classification of dwarf mistletoes (*Arceuthobium*). U.S. Department of Agriculture, Forest Service, Agricultural Handbook No. 410, 204 p. Washington, D.C.

Hinds, T. E. 1977. Heart rots of Engelmann spruce and subalpine fir in the central Rocky Mountains. U.S. Department of Agriculture, Forest Service, Forest Insect and Disease Leaflet 150, 8 p. Rocky Mountain Forest and Range Experiment Station, Washington, D.C.

Hinds, Thomas E., and Frank G. Hawksworth. 1966. Indicators and associated decay of Engelmann spruce in Colorado. USDA Forest Service Research Paper RM-25, 15 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Hinds, Thomas E., Frank G. Hawksworth, and Ross W. Davidson. 1960. Decay of subalpine fir in Colorado. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Station Paper 51, 13 p. Fort Collins, Colo.

Hodson, E. R., and J. H. Foster. 1910. Engelmann spruce in the Rocky Mountains. U.S. Department of Agriculture, Forest Service, Circular 170, 23 p. Washington, D.C.

Hoover, Marvin D., and Charles F. Leaf. 1965. Process and significance of interception in Colorado subalpine forest. p. 213-224. *In* W. E. Sopper and H. W. Lull, editors. Forest Hydrology: International Symposium on Forest Hydrology [University Park, Penn., Aug.-Sept. 1965]. Pergamon Press, New York, N.Y.

Hopkins, A. D. 1909. Practical information on the scolytid beetles in North American forests. I. Barkbeetles of the genus *Dendroctonus*. U.S. Department of Agriculture, Entomology Bulletin 83, pt. 1, 169 p. Washington, D.C.

Hornibrook, E. M. 1950. Estimating defect in mature and over mature stands of three Rocky Mountain conifers. Journal of Forestry 48:408-417.

Kaplan, R. 1973. Predictors of environmental preferences. Designers and "clients." p. 265-274. *In* W. F. E. Prieser, editor. Environmental Design Research. Proceedings of fourth international EDRA conference. [Blacksburg, Va, April 1973]. Dowden, Hutchinson, and Ross, Stroudsburg, Penn.

Keen, F. P. 1952. Insect enemies of western forests. U.S. Department of Agriculture, Miscellaneous Publication 273, 280 p. Washington, D.C.

Knight, F. B., W. F. McCambridge, and B. H. Wilford. 1956. Estimating Engelmann spruce beetle infestations in the central Rocky Mountains. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Station Paper 25, 12 p. Fort Collins, Colo.

Leaf, C. F. 1970. Sediment yields from central Colorado snow zone. American Society of Civil Engineering, Journal of Hydraulic Division 96(HY1):87-93, 97(HY2): 350-351.

Leaf, Charles F. 1975. Watershed management in the Rocky Mountain subalpine zone: The status of our knowledge. USDA Forest Service Research Paper RM-137, 31 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Leaf, Charles F., and Robert R. Alexander. 1975. Simulating timber yields and hydrologic impacts resulting from timber harvest on subalpine watersheds. USDA Forest Service Research Paper RM-133, 20 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

LeBarron, Russell K., and George M. Jemison. 1953. Ecology and silviculture of the Engelmann spruce-subalpine fir type. Journal of Forestry 51:349-355.

Martinka, Robert R. 1972. Structural characteristics of blue grouse territories in southwestern Montana. Journal of Wildlife Management 36:489-510.

Massey, C. L., and N. D. Wygant. 1954. Biology and control of the Engelmann spruce beetle in Colorado. U.S. Department of Agriculture, Circular 944, 35 p. Washington, D.C.

Mathiasen, R. L., and F. G. Hawksworth. 1983. Dwarf mistletoes on true firs in the Southwest. Northern Arizona University, School of Forestry, Arizona Forestry Notes No. 18, 12 p. Flagstaff, Ariz.

McCaughey, Ward W., and Wyman C. Schmidt. 1982. Understory tree release following harvest cutting in spruce-fir forests of the Intermountain West. USDA Forest Service Research Paper INT-285, 19 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Meyer, H. A. 1952. Structure, growth and drain in balanced uneven-aged forests. Journal of Forestry 50:85-92.

Meyer, H. A., A. D. Recknagel, D. D. Stevenson, and R. A. Bartoo. 1961. Forest Management. 282 p. The Roland Press Company, New York, N.Y.

Miller, Phillip C. 1970. Age distributions of spruce and fir in beetle-killed stands on the White River Plateau. American Midland Naturalist 83:206-212.

Myers, C. A., and M. J. Morris. 1975. Watershed management practices and habitat values in coniferous forests. p. 288-294. *In* Proceedings, Symposium on management of forest and range habitats for nongame birds. [Tucson, Ariz., May 6-9, 1975]. USDA Forest Service General Technical Report WO-1, 6 p. Washington, D.C.

Nagel, R. H., David McComb, and F. B. Knight. 1957. Trap tree method for controlling the Engelmann spruce beetle in Colorado. Journal of Forestry 55:894-898.

Noble, Daniel L., and Frank Ronco. 1978. Seedfall and the establishment of Engelmann spruce and subalpine fir in clearcut openings in Colorado. USDA Forest Service Research Paper RM-200, 12 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Oosting, Henry J., and John F. Reed. 1952. Virgin spruce-fir in the Medicine Bow Mountains, Wyoming. Ecology Monograph 22:69-91.

Peterson, Roger S. 1963. Effects of broom rusts on spruce and fir. USDA Forest Service Research Paper INT-7, 10 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Regelin, Wayne L., Olof C. Wallmo, Julius G. Nagy, and Donald R. Dietz. 1974. Effect of logging on forage values for deer in Colorado. Journal of Forestry 72:282-285.

Regelin, Wayne L., and Olof C. Wallmo. 1978. Duration of deer forage benefits after clearcut logging of subalpine forest in Colorado. USDA Forest Service Research Note RM-356, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Retzer, John L. 1956. Alpine soils of the Rocky Mountains. Journal of Soil Science 7:22-32.

Reynolds, Hudson G. 1966. Use of openings in spruce fir forests by deer, elk and cattle. USDA Forest Service Research Note RM-63, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Reynolds, R. R. 1954. Growing stock in all-aged forests. Journal of Forestry 52:744-747.

Roe, Arthur L. 1967. Seed dispersal in a bumper spruce seed year. USDA Forest Service Research Paper INT-39, 10 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Roe, Arthur L., Robert R. Alexander, and Milton D. Andrews. 1970. Engelmann spruce regeneration practices in the Rocky Mountains. USDA Forest Service, Production Research Report 115, 32 p. Washington, D.C.

Roe, Arthur L., and G. M. DeJarnette. 1965. Results of regeneration cutting in a spruce-subalpine fir stand. USDA Forest Service Research Paper INT-17, 4 p. Intermountain Forest and Range Experiment Station, Ogden, Utah.

Ronco, Frank. 1970. Shading and other factors affect survival of planted Engelmann spruce seedlings in central Rocky Mountains. USDA Forest Service Research Note RM-163, 7 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Schmid, John M. 1977. Guidelines for minimizing spruce beetle populations in logging residuals. USDA Forest Service Research Paper RM-185, 8 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Schmid, John M., and Roy C. Beckwith. 1971. The Engelmann spruce beetle. U.S. Department of Agriculture, Forest Service, Forest Pest Leaflet 127, 7 p. Washington, D.C.

Schmid, J. M., and R. H. Frye. 1977. Spruce beetle in the Rockies. USDA Forest Service General Technical Report RM-49, 38 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Schmid, J. M., and T. E. Hinds. 1974. Development of spruce-fir stands following spruce beetle outbreaks. USDA Forest Service Research Paper RM-131, 16 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Scott, Virgil E., Glenn L. Crouch, and Jill A. Whelan. 1982. Responses of birds and small mammals to clearcutting in a subalpine forest in central Colorado. USDA Forest Service Research Note RM-422, 6 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Scott, Virgil E., Jill A. Whelan, and Robert R. Alexander. 1978. Dead trees used by cavity-nesting birds on the Fraser Experimental Forest: A case history. USDA Forest Service Research Note RM-360, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Society of American Foresters. 1980. Forest cover types of the United States and Canada. 148 p. F. H. Eyre, editor. Washington, D.C.

Stahelin, R. 1943. Factors influencing the natural restocking of high altitude burns by coniferous trees in the central Rocky Mountains. Ecology 24:19-30.

Stevens, Robert E. 1971. Fir-engraver. U.S. Department of Agriculture, Forest Pest Leaflet 13, 7 p. Washington, D.C.

Stottlemeyer, J. R., and C. W. Ralston. 1968. Nutrient balance relationships for watersheds on the Fraser Experimental Forest. p. 3:359-382. *In* Proceedings North American forest soils conference. [Raleigh, N.C., 1968]. North Carolina State University.

Sudworth, George B. 1900a. White River Plateau timber land reserve. p. 117-179. *In* Twentieth annual report, 1898-1899. Part V Forest Reserves. U.S. Geological Survey, Washington, D.C.

Sudworth, George B. 1900b. Battlement Mesa forest reserve. p. 181-243. *In* Twentieth annual report, 1898-1899. Part V Forest Reserves. U.S. Geological Survey, Washington, D.C.

Troendle, Charles A. 1982. The effects of small clearcuts on water yield from the Deadhorse watershed; Fraser, Colorado. p. 75-83. *In* Proceedings, 50th annual meeting of the Western Snow Conference. [Reno, Nev., April 19-23, 1982]. Colorado State University, Fort Collins, Colo.

Troendle, Charles A. 1983a. The Deadhorse experiment: A field verification of the subalpine water balance model. USDA Forest Service Research Note RM-425, 7 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Troendle, C. A. 1983b. The potential for water yield augmentation from forest management in the Rocky Mountain Region. American Water Resources Association, Water Resources Bulletin 19:359-373.

Troendle, Charles A., and Charles F. Leaf. 1981. Effects of timber harvesting in the snow zone on volume and timing of water yield. p. 231-243. *In* David A. Baumgartner, editor and compiler. Proceedings, Interior West Watershed Symposium. [Spokane, Wash., April 8-10, 1980]. Cooperative Extension, Washington State University, Pullman, Wash.

Troendle, Charles A, and James E. Meiman. 1984. Options for harvesting timber to control snowpack accumulation. p. 86-98. *In* Proceedings, 52nd Annual Meeting of the Western Snow Conference. [Sun Valley, Idaho, April 17-19, 1984]. Colorado State University, Fort Collins, Colo.

U.S. Department of Agriculture, Forest Service. 1933. Annual report (twenty-third year). (1932) Mimeograph Rocky Mountain Region. Rocky Mountain Forest and Range Experiment Station, Washington, D.C.

U.S. Department of Agriculture, Forest Service. 1983. Silvicultural systems for the major forest types of the United States. R. E. Burns, technical compiler. Agricultural Handbook No. 445. Washington, D.C.

Wallmo, O. C. 1969. Response of deer to alternate-strip clearcutting of lodgepole pine and spruce-fir timber in Colorado. USDA Forest Service Research Note RM-141, 4 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Wallmo, O. C., W. L. Regelin, and D. W. Reichert. 1972. Forage use by mule deer relative to logging in Colorado. Journal of Wildlife Management 36:1025-1033.

Whipple, Stephen A., and Ralph L. Dix. 1979. Age structure and successional dynamics of a Colorado subalpine forest. American Midland Naturalist 101: 142-158.

Whiteside, J. M., and V. M. Carolin, Jr. 1961. Spruce budworm in the western United States. U.S. Department of Agriculture, Forest Service, Forest Pest Leaflet 53, 8 p. Washington, D.C.

Wygant, N. D. 1958. Engelmann spruce beetle control in Colorado. *In* Proceedings, 10th International Congress of Entomology, No. 4:181-184.

Wygant, N. D., and R. R. LeJeune. 1967. Engelmann spruce beetle *Dendroctonus obesus* (Mann) (= *D. engelmannii* Hopk.). p. 93-95. *In* Important forest insects and diseases of mutual concern to Canada, the United States and Mexico. Publication 1180. Canadian Department of Forest and Rural Development, Ottawa, Ont.

Alexander, Robert R. 1986. Silvicultural systems and cutting methods for old-growth spruce-fir forests in the central and southern Rocky Mountains. USDA Forest Service General Technical Report RM-126, 33 p. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.

Guidelines are provided to help the forest manager and silviculturist develop even- and/or uneven-aged cutting practices needed to convert old-growth spruce-fir forests into managed stands for a variety of resource needs. Guidelines consider stand conditions, succession, windfall risk, and insect and disease susceptibility. Cutting practices are designed to integrate timber production with increased water yield, maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic viewing.

Keywords: Silvicultural systems, timber harvesting, forest resources, *Picea engelmannii, Abies lasiocarpa*

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Guidelines are provided to help the forest manager and silviculturist develop even- and/or uneven-aged cutting practices needed to convert old-growth spruce-fir forests into managed stands for a variety of resource needs. Guidelines consider stand conditions, succession, windfall risk, and insect and disease susceptibility. Cutting practices are designed to integrate timber production with increased water yield, maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic viewing.

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U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

Rocky Mountains

Southwest

Great Plains

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota
Tempe, Arizona

*Station Headquarters: 240 W. Prospect St., Fort Collins, CO 80526